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Guidance Manual on Overtopping Control Techniques for Hazardous Waste Impoundments

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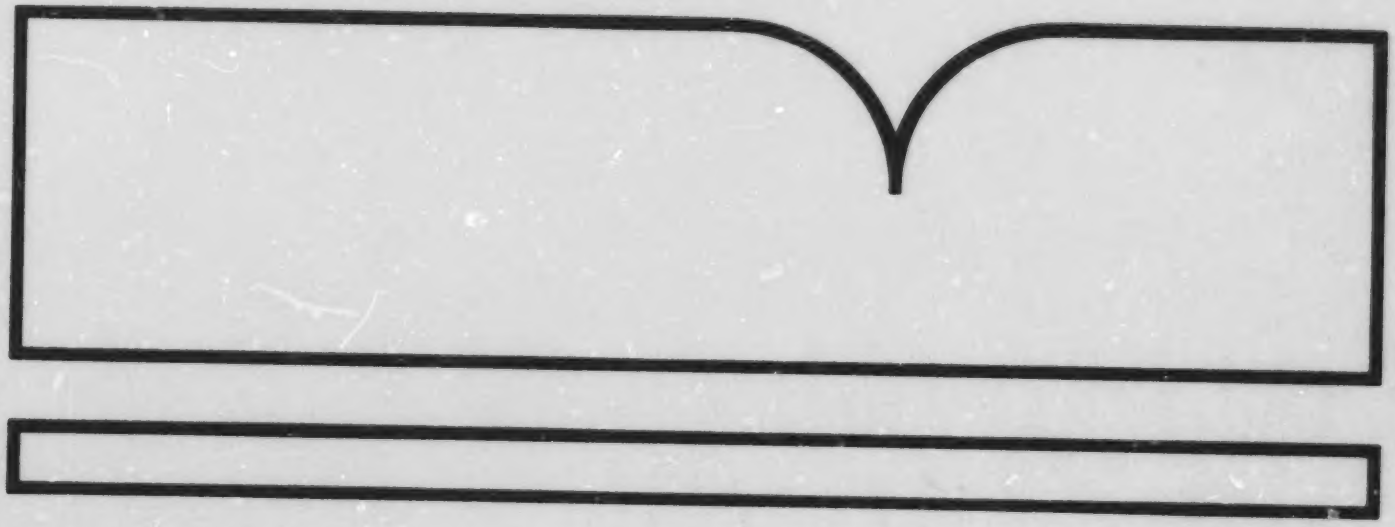

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GUIDANCE MANUAL ON OVERTOPPING CONTROL TECHNIQUES FOR HAZARDOUS WASTE IMPOUNDMENTS

by

Virginia Hodge
Nick DeSalvo
Shahid Mahmud
Joshua Margolis
Mark Evans
John Meade
JRB Associates
McLean, Virginia 22102

Contract No. 68-03-3113

Project Officer

Anthony N. Tafuri
Hazardous Waste Engineering Research Laboratory
Releases Control Branch
Edison, NJ 08837

HAZARDOUS WASTE ENGINEERING RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
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16. ABSTRACT The overall objective of this project was to provide guidance for selecting cost-effective interim management methods to control overtopping of impoundments, pits, ponds, or lagoons at uncontrolled hazardous waste sites until final remedial actions could be initiated.

Hazardous waste impoundments are subject to overtopping through the collection of rainwater, run-on, or other uncontrolled inflow. Lagoon overflows are generally the result of insufficient capacity due to either insufficient freeboard (high level of lagoon contents) or structural problems that reduce the effective capacity. No matter what the cause, lagoon overflows can pose significant environmental and public health risks through the contamination of soils, groundwater, and surface water, as well as the potential to spread the contamination into areas not currently impacted by the lagoon. Thus interim measures may be necessary to control lagoon overflows prior to identification and selection of a final remedial measure.

A manual has been prepared that addresses both immediate control measures for emergencies and longer term measures lasting several months to several years. The technology and cost guidance presented is general in nature because of the variability of waste lagoons and impoundments and the unique conditions and considerations that exist at each site. Where possible, factors affecting application, technology selection, and costs are identified, as well as their likely impact on implementation and cost-effectiveness. Design issues are briefly presented as background to each option; however, the manual is not intended to replace the services of a qualified engineer in designing site-specific systems.

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This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of solid and hazardous wastes. These materials, if improperly dealt with, can threaten both public health and the environment. Abandoned waste sites and accidental releases of toxic and hazardous substances to the environment also have important environmental and public health implications. The Hazardous Waste Engineering Research Laboratory assists in providing an authoritative and defensible engineering basis for assessing and solving these problems. Its products support the policies, programs, and regulations of the Environmental Protection Agency, the permitting and other responsibilities of State and local governments and the needs of both large and small businesses in handling their wastes responsibly and economically.

The Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) established a nationwide program for the cleanup of uncontrolled hazardous waste sites. Under this program, uncontrolled waste sites are identified and ranked, and removal or remedial actions are identified, studied, and implemented to eliminate or reduce contamination problems. Interim measures must often be applied to prevent or reduce further environmental contamination or threat to public health until final actions can be taken. The objective of this manual is to provide guidance on selecting cost-effective interim management methods to control overtopping of impoundments, pits, ponds, or lagoons at uncontrolled hazardous waste sites. For further information, please contact the Land Pollution Control Division of the Hazardous Waste Engineering Research Laboratory.

David G. Stephan, Director
Hazardous Waste Engineering
Research Laboratory

ABSTRACT

This manual is intended to provide guidance on selecting cost-effective interim management methods to control overtopping of impoundments, pits, ponds, or lagoons at uncontrolled hazardous waste sites until final remedial actions can be initiated.

Hazardous waste impoundments are subject to overtopping through the collection of rainwater, run-on, or other uncontrolled inflow. Lagoon overflows are generally the result of insufficient lagoon capacity due to either insufficient freeboard (high level of lagoon contents) or structural problems that reduce the effective capacity. No matter what the cause, lagoon overflows can pose significant environmental and public health risks through the contamination of soils, groundwater, and surface water, as well as the potential to spread the contamination into areas not currently impacted by the lagoon. Thus, interim measures may be necessary to control lagoon overflows prior to identification and selection of a final remedial measure.

This manual addresses both immediate control measures for emergencies and longer term measures lasting several months to several years. The technology and cost guidance presented is general in nature because of the variability of waste lagoons and impoundments, and the unique conditions and considerations that exist at each lagoon site. Where possible, factors affecting application, technology selection, and costs are identified, as well as their likely impact on implementation and cost-effectiveness. Design issues are briefly presented as background to each option; however, this manual is not intended to replace the services of a qualified design engineer in designing site-specific systems.

The document presents the selection process for overtopping control decisionmaking and key factors affecting selection decisions. Details are provided on each option; pumping and wastewater management options; structural, floating, and air-supported cover systems; and surface water diversion and berm reconstruction technologies.

This report was submitted in partial fulfillment of Contract No. 68-03-3113 by JRB Associates under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period from March, 1983 to September, 1984, and work was completed on September 30, 1984.

CONTENTS

Foreword iii
Abstract iv
Figures vi
Tables viii
Acknowledgements ix

1. Introduction 1
   Overtopping Control Measures 1
   Impoundment Characterization 1
   Manual Content 2
2. Selection of Overtopping Control Measures 3
   Characterization of Overtopping Problem 3
   Identification of Applicable Response Options 5
   Definition of Relevant Site Characteristics 7
   Evaluation and Selection of Overtopping Controls . . . 7
3. Pumping and Wastewater Management 27
   Pumping Systems 27
   Wastewater Management 33
   Summary 41
4. Lagoon Cover Systems 43
   Frame-Supported Tension Membrane Structures 43
   Prefabricated Steel Frame Buildings 48
   Air-Supported Structures 51
   Floating Cover Systems 59
5. Surface Water Diversion and Berm Improvements 66
   Surface Water Controls 66
   Impoundment Wall Contruction and Repair 89

References 93
Appendices

A. List of Company Addresses 95
B. Conversion Factors 96

FIGURES

Number		Page
2-1	Process for Selecting Lagoon Overtopping Control Measures. .	4
3-1	Flow Diagram of Pumping and Wastewater Management Options to Control Waste Lagoon Overtopping.	28
4-1	Frame-Supported Tension Membrane Structures.	44
4-2	Typical Cross-Section of the Portomod Structure.	46
4-3	Prefabricated Steel Frame Structures	49
4-4	Air-Supported Structure (Thermo-Flex).	53
4-5	Earth Anchorage System	54
4-6	Concrete Anchorage System.	55
4-7	Extruded Anchorage System.	56
4-8	Channel Anchorage System	57
4-9	Schematic Plan and Cross-Section of a Floating Cover Incorporating the Patented Globe Design.	61
4-10	Schematic Plan and Cross-Section of a Floating Cover Incorporating the Patented Burke Design.	62
4-11	Schematic Plan and Cross-Section of a Patented Globe Floating Cover and Gas Collection System Design.	64
5-1	Standard Design for Drainage Ditches	68
5-2	General Design Features of Diversions.	69
5-3	Temporary Diversion Dike	70
5-4	Grassed Waterways with Stone Center.	71
5-5	Temporary Interceptor Dike	78
5-6	Bench Terraces with Reverse Fall	81
5-7	Typical Drainage Bench	82

FIGURES (continued)

Number		Page
5-8	Slope Reduction Measures	83
5-9	Levee Configuration.	86
5-10	Typical Floodwall Sections	88

TABLES

Number		Page
2-1	Decision Matrix for Selecting Overtopping Controls	6
2-2	Site-Related Factors Affecting Response Technology Selection	10
2-3	Summary Table for Pumping Systems	16
2-4	Summary Table for Wastewater Management Options	17
2-5	Summary Table for Cover Systems	19
2-6	Summary Table for Surface Water Controls	21
2-7	Summary Table for Impoundment Wall Improvements	26
3-1	Pump Costs	32
3-2	Rental Costs for Pumps and Hoses	34
3-3	Material of Construction Cost Factors for Storage Tanks	37
3-4	Estimated Costs of Liquid Level Indicator and Control Systems	38
3-5	Cost Estimates for Treating Wastewater	40
3-6	Selected Mobile Treatment Costs	42
5-1	Unit Costs Associated with Surface Water Diversion and Collection Structures	73

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SECTION 1

INTRODUCTION

The Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) established a nationwide program for the cleanup of uncontrolled hazardous waste sites. Under this program, uncontrolled waste sites are identified and ranked, and removal or remedial actions are identified, studied, and implemented to eliminate or reduce contamination problems. Interim measures must often be applied to prevent or reduce further environmental contamination or threat to public health until final actions can be taken. The objective of this manual is to provide guidance on selecting cost-effective interim management methods to control overtopping of impoundments, pits, ponds, or lagoons at uncontrolled hazardous waste sites.

OVERTOPPING CONTROL MEASURES

Impoundments are subject to overtopping through the collection of rainwater, precipitation run-off (site run-on), or other uncontrolled liquid inflow. Lagoon overflows are generally the result of insufficient lagoon capacity due to either insufficient freeboard (high level of lagoon contents) or structural problems that reduce the effective capacity. No matter what the cause, lagoon overflows can pose significant environmental and public health risk through the contamination of soils, groundwater, and surface water as well as the potential to spread the contamination into areas not currently impacted by the lagoon. Thus, response measures may be necessary to control lagoon overflows prior to identification and selection of a final response measure.

Typical response actions to temporarily control an overflow problem have included reconstruction of the impoundment berm to increase the freeboard, removal of liquid to lower the lagoon level, or both. However, other response methods such as run-on diversions and covers are available and may often be more cost-effective.

IMPOUNDMENT CHARACTERIZATION

There are currently 180,000 active and abandoned surface impoundments in the United States (U.S. EPA, 1983). A recent assessment study conducted by the U.S. Environmental Protection Agency (EPA) indicates that there are at least 4,700 abandoned surface impoundments; EPA estimates that the actual number may be much higher (U.S. EPA, 1983).

Surface impoundments are highly variable in size, structure, design, and purpose. Lagoons have been used for treatment, storage, or disposal of liquid, solid, and semi-solid wastes from industrial, mining, oil and gas, and agricultural operations. They may be square, rectangular, circular, or irregular in shape and may be unlined to permit seepage to underlying soils or lined to prevent seepage. Furthermore, lagoons may be built above the ground surface or into the ground via natural or manmade depressions. Commonly, more than one surface impoundment may be found at a particular site and these multiple impoundments may be interconnected.

These features, in conjunction with site-specific characteristics, can significantly affect the choice of overtopping control measures.

MANUAL CONTENT

This manual has been prepared to provide technical guidance to On-Scene Coordinators (OSCs); Federal, state, and local officials; private firms; and EPA field personnel. It represents a decision guide on impoundment overtopping controls as a temporary solution pending final response action. As such, it addresses both immediate control measures for emergencies and longer term measures lasting several months to several years.

The technology and cost guidance presented is general in nature because of the variability of waste lagoons and impoundments and the unique conditions and considerations that exist at each lagoon site. Where possible, factors affecting application, technology selection, and costs are identified as well as their likely impact on implementation and cost-effectiveness. Furthermore, while design issues are briefly presented as background to each option, this manual is not intended to replace the services of a qualified design engineer in designing site-specific systems.

The manual is organized as follows. Section 2 presents the selection process for overtopping control decisionmaking and key factors affecting selection decisions. Sections 3 through 5 present further detail on the information summarized in Section 2 for each option. Section 3 describes pumping and wastewater management options. Section 4 presents structural, floating, and air-supported cover systems. Section 5 describes surface water diversion and berm reconstruction technologies.

SECTION 2

SELECTION OF OVERTOPPING CONTROL MEASURES

The selection of overtopping control measures proceeds in four steps:

- o Identify and define the overtopping problem
- o Identify applicable response options
- o Define relevant site characteristics
- o Evaluate and select a cost-effective response.

Figure 2-1 illustrates this selection process.

The first step in this selection process is identification of the site problem; specifically, why the lagoon overflows and what site location or characteristics contribute to the overflow. At the same time, the site situation is assessed regarding the need for immediate emergency measures to be applied prior to identifying further interim control measures.

The second step involves a preliminary selection of response options that may be applicable based on the site problem. Thus, the first and second steps of the selection process are closely linked.

The third step involves an evaluation of site characteristics affecting the applicability of a particular response. These characteristics are defined by the response technologies identified in Step 2 and are critical to the final evaluation and selection of a response in Step 4.

The fourth step involves selecting a single response option or combination of options that best controls the overflow problem until the final site action is selected. This selection process is highly site-specific and requires consideration of site-related decision factors relative to the applicable technologies and their costs.

These steps are described in more detail in the following sections.

CHARACTERIZATION OF OVERTOPPING PROBLEM

The causes of waste lagoon overtopping fall into two general categories:

- o Insufficient lagoon capacity to accommodate liquid inflows to the lagoon
- o Reduced lagoon capacity due to structural damage to the upper portion of the lagoon berm.

Insufficient capacity may be the result of insufficient freeboard in the lagoon, precipitation, run-on, or overflows/liquid feeds from a connecting lagoon or other system. Structural damage reducing the effective lagoon capacity would include erosion, cracks, subsidence, breach, or other penetration of the lagoon berm in the area of the lagoon level.

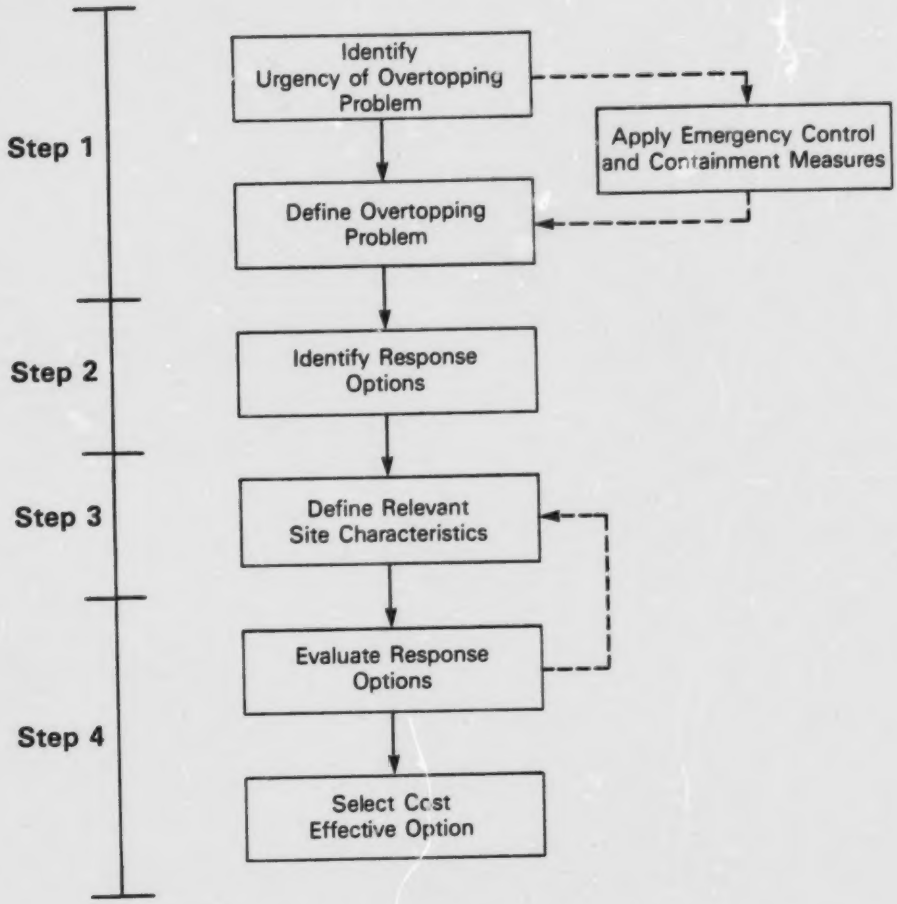


Figure 2-1. Process for Selecting Lagoon Overtopping Control Measures

Lagoon overflows may result from single or multiple causes. An example of a single cause would be precipitation adding liquid volume to the lagoon. Multiple causes such as precipitation and run-on or precipitation and subsidence in a portion of the berm are more complex to evaluate and resolve.

In general, the nature of the overtopping problem is highly site specific. It must be evaluated in terms of the causal and contributing factors. For example, a crack in the top of an impoundment berm reduces the capacity of the lagoon if it penetrates from the interior berm wall to the exterior. Where the crack or break is sufficiently deep, there may be a single event of lagoon spillage. However, precipitation may quickly cause an overflow to recur.

Thus, the first step in selecting appropriate overtopping control measures is to identify the problem, including both the cause and the contributing factors. Once the reasons for the lagoon overflow have been defined, they can be used to identify potential actions to control the general problem until a final site action is developed.

If the lagoon is overflowing or overflow is imminent, immediate control measures are required. These control measures consist of constructing a temporary holding pond to contain the overflow or using a temporary pumping system to lower the lagoon level. Once the urgency of the problem has been reduced, appropriate control measures for the interim period prior to response should be identified and implemented. These measures will supplement or replace the stop-gap measures employed to control the immediate problem by identifying and addressing the contributing factors.

IDENTIFICATION OP APPLICABLE RESPONSE OPTIONS

Table 2-1 presents a decision matrix for general selection of overtopping controls. This matrix matches overtopping problems with the most applicable response options. Each problem has a choice of several technologies that may be applied. The selection of a single response will depend on site-specific factors as described in Step 4 later in this section.

Where more than one problem is involved (causal or contributing), the response options are expanded. As shown in Table 2-1, possible responses for overflow caused by precipitation are pumping or covering the lagoon or raising the berm height. If both precipitation and run-on are causing lagoon overflow, the response options expand to include run-on diversions. Furthermore, the selected response may involve a single response option (e.g., pumping) or a combination of response options (e.g., construct diversion, pump, and cover).

It should be noted that certain response options require specific associated responses, as noted in Table 2-1. Pumping lagoons to remove liquid and increase freeboard requires management of the waste liquid. Similarly, raised covers such as air-supported and arch-supported structures may require vapor or condensate control to prevent the buildup of hazardous gases inside the structures or release of liquids outside the lagoon berm. These requirements can be met through a variety of methods as described in the appropriate technology discussions in Sections 3 through 5. However, the impact of these requirements

TABLE 2-1. DECISION MATRIX FOR SELECTING OVERTOPPING CONTROLS

Overtopping Problem	Primary Response Options	Associated Responses	Additional Considerations
Insufficient Capacity for Liquid Inputs			
o Precipitation	Pump Cover Raise berm	Wastewater management options Vapor/condensation controls	Temporary vs. permanent pumping One-time vs. recurrent pumping needs Response option combinations
o Run-on	Pump Raise berm Construct diversion(s)	Wastewater management options	Temporary vs. permanent pumping One-time vs. recurrent pumping needs Response option combinations
o Overflow from connecting lagoon	Pump Raise berm Reduce connecting overflow	Wastewater management options	Temporary vs. permanent pumping One-time vs. recurrent pumping needs Response option combinations
Reduced Capacity Due to Structural Damage	Pump (use as smaller capacity lagoon) Reconstruct/repair berm	Wastewater management options	Temporary vs. permanent pumping One-time vs. recurrent pumping needs Response option combinations Response option combinations with technologies for insufficient capacity, above

is to increase the number of response option combinations to be considered in the selection process.

DEFINITION OF RELEVANT SITE CHARACTERISTICS

Table 2-2 summarizes the lagoon- and site-related features that will affect selection of overtopping controls. Such features as lagoon structure, lagoon contents, and site characteristics will determine the need to develop multi-technology response options (where several technologies are used in combination) or eliminate competing technology responses. This table is not intended to be exhaustive with respect to the factors listed or their range of impact, nor do all factors listed apply to all technologies. Rather, it identifies many of the major site features and considerations and provides a general idea of their relationship to the technologies described in this manual.

EVALUATION AND SELECTION OF OVERTOPPING CONTROLS

A specific control measure is selected based on technology and site-related decision factors. This process involves a simple cost-effectiveness evaluation to decide among competing control responses. The control responses may consist of one or more response options.

This decision process is the culmination of the assessments conducted in the previous sections to select from the options and option combinations available. The applicable options are identified based on site problems and factors contributing to overtopping. To select an option, all of these options and their combinations should be evaluated based on the site criteria identified in Step 3 (Figure 2-1), the technology criteria identified in this section as well as Sections 3 through 5, and general cost estimates based on site characteristics and anticipated system needs.

Tables 2-3 through 2-7 at the end of this section are summary tables for the potentially applicable technologies: pumping, wastewater management, lagoon cover systems, berm reconstruction, and surface water (run-off/run-on) diversion systems. These tables present specific, decision-related criteria regarding technology applicability, limitations, and costs. Further detail on the technologies is provided in Sections 3, 4, and 5; these actions should be reviewed for system features, general guidance on their applicability, and more detailed cost data.

The technology evaluation should screen the options based on applicability to the site problem (defined through the site criteria) as well as the potential to reuse any permanent systems or materials or the need to demolish structures such as covers or diversion structures for final site action. The reuse of a system will impact its cost-effectiveness since the capital investment is spread among several applications. Alternatively, the removal of a cover and its anchoring system or the demolition of diversion structures may impact the costs of the final response action at the site.

Other criteria included in the technology evaluation are:

- o Anticipated length of time before final response measures are implemented at the site
  - Short time intervals (less than 3 months) would support a pumping system or diversion structures.
  - Long time intervals (3 to 5 years) would support cover systems.
- o Urgency of problem
  - Where lagoon overflow is imminent, pumping or construction of a temporary holding pond would be indicated.
  - Where the situation is less urgent, pumping may be used as an initial measure prior to another control response or pumping may be implemented as a control measure.
- o Time to implement control measures
  - Cover systems will require more time to implement than the use of pumps or site reconstruction.
- o Size of lagoon
  - Structural covers cannot be used where the smallest dimension exceeds the greatest width available (see Table 2-4).
  - Multiple pumping stations or berm reconstruction may be more cost-effective than a floating cover for large lagoons.
  - Covers may be more applicable to small to moderate lagoons where frequent pumping may be necessary.
- o Volume of liquid to be removed
  - Areas with heavy or frequent rainfall would favor a permanent pumping station, berm reconstruction, diversion structures, a cover, or a combination of these options.
  - Areas with isolated precipitation events would favor temporary pumping stations.

As part of the cost-effectiveness evaluation, the costs presented in Tables 2-3 through 2-7 may be used for general estimates of costs to compare one response with another. The costs developed will depend on the technology. For example, cover costs are $\$/ft^2$ (area covered), pump rental costs are \$/day, and excavation costs are $\$/yd^3$ (material moved). The costs should be compared on a uniform basis. One method would be to average the cost over the length of time that the control measure is in effect; in such cases, the costs should include gross estimates of maintenance, inspection, and repair activities that would be likely within the time period.

The cost estimates in Tables 2-3 through 2-7 are considered to be general in nature for the purposes of rapid comparisons and decisionmaking. Detailed cost guidance is available in EPA procedural manuals where such costing may be necessary.

Both the technology and cost comparisons should consider single-response options and multiple-response options. In some instances, a technologically complex solution may be more cost-effective than a technologically simpler solution. For example, under certain conditions it may be more cost-effective to install a floating cover on a lagoon (including an initial pumpdown and some berm strengthening) to control overflow resulting from precipitation rather than to pump down the lagoon level several times a year while the final response action is under study. Of course, this decision depends on the expected length of time before final measures are implemented, on technology costs, and on-site features such as precipitation patterns, as described above.

Of special importance is the evaluation of pumping options. Either a temporary pumping system can be brought in when needed or a permanent pumping system can be constructed. The decision between the two would depend on the number of times pumping would be necessary and the relationship of pumping to other options considered in the response. For example, a one-time pumping situation, whether as a single-response action or in conjunction with another option such as berm reconstruction, would generally involve a temporary pumping system. However, where frequent pumpouts are necessary (e.g., due to heavy annual rainfall), a permanent pumping station could be selected unless a more cost-effective control option is available. Lagoon size, volume of liquid to be pumped, frequency of pumping, and wastewater management requirements would all affect the selection of this option.

Wastewater management options also involve a complex evaluation. Wastewater management is always necessary in conjunction with pumping. Management options involve a number of on-site and off-site methods to store, transport, treat, or dispose of pumped liquids. Furthermore, many of these options can be conducted together and many combinations are possible. Key decision factors will involve the type of pumping system selected (temporary or permanent), wastewater quantities, wastewater characteristics, available facilities, etc. It may be necessary to evaluate and conduct several general cost estimates for several combinations of options.

Finally, vendors are an excellent source of information regarding the applicability and costs of their systems on a site-specific basis. They may be able to provide information relevant to a site that can assist in the selection effort.

TABLE 2-2. SITE-RELATED FACTORS AFFECTING RESPONSE TECHNOLOGY SELECTION

Site-Related Factor	Criterion	Impact
Lagoon/impoundment design, construction, and condition	Dimensions/shape/size	Suitability of size for dimension-limited covers
		Determination of volume of liquid to be pumped
	Liner	Location of support beams and other technology-related systems to prevent puncture
	Location (one area, hillside)	Determine potential for run-on or flooding problems
		Affect on construction or technology design options
	Multiple impoundment system	Additional inflow sources or outflow recipients to be controlled or used as part of the controlling response
	Erosion/structural degradation of berm	Need to reconstruct/repair berm alone or in conjunction with other technologies

(continued)

TABLE 2-2. (continued)

Site-Related Factor	Criterion	Impact
Lagoon/impoundment design, construction, and condition	Structural integrity	Need to reconstruct/repair berm alone or in conjunction with other technologies
		Need to reduce lagoon level to minimize outflow potential due to structural failure
	Materials of construction	Load-bearing capability may affect selection or design of berm reconstruction or cover systems
	Freeboard	Need for initial pumping regardless of control technology selected
		Determination of volume of liquid to be pumped
	Inflow/outflow systems	Additional systems requiring control or used as part of controlling response
Lagoon/impoundment contents	Materials/chemicals	Selection of compatible materials in control technology (e.g., cover material, pump specifications, berm material)
		Selection of storage tank materials

(continued)

TABLE 2-2. (continued)

Site-Related Factor	Criterion	Impact
Lagoon/impoundment contents	Chemical concentration	Selection of compatible materials in control technology (e.g., cover material, pump specifications, berm material)
		Selection of wastewater management method (e.g., POTW limitations, commercial treatment facility options)
		Selection of storage tank materials
	Liquids stratification	Type of wastewater generated from pumping
	Volatility	Need for vapor controls with conventional or air-supported structures or storage tanks
	Explosive potential	Need for vapor controls with conventional or air-supported structures
		Selection of pumping mechanism
	Physical characteristics (viscosity, density, particulates, solids)	Selection of appropriate pump type

(continued)

TABLE 2-2. (continued)

Site-Related Factor	Criterion	Impact
Lagoon/impoundment contents	Chemical characteristics (BOD, COD, etc.)	Selection of wastewater management options
	Debris	Need for debris removal prior to response
		Need for protective screens or pump intake
		Large non-removable objects may preclude certain technologies such as floating covers
Site characteristics	Access	Ability to bring in construction equipment/materials
	Utilities (sewer, power)	Ability to use local POTW for wastewater treatment
		Ability to use an air-supported cover
		Ability to install permanent, automatic pumping station
	Soils (structural, load-bearing support)	Ability to support structures such as large tanks
		Ability to support construction equipment or tank trucks

(continued)

TABLE 2-2. (continued)

Site-Related Factor	Criterion	Impact
Site characteristics	Hydrogeology	Capability of lagoon to adjust to rainfall or run-on
		Need for run-on controls
	Security	Need for technology-specific security needs to prevent/ minimize vandalism problems
	Precipitation (quantity, frequency)	Determination of volume and frequency of pumping needs
		Selection of pumping system based on volume to be removed
		Selection between permanent or temporary pump system
		Selection of storage tank size or number of tank trucks needed
	Wind patterns (direction, force)	Potential for wave-induced overflow or berm erosion
		Selection of erosion controls in berm reconstruction

(continued)

TABLE 2-2. (continued)

Site-Related Factor	Criterion	Impact
Site characteristics	Run-on	Need for diversion system alone or in conjunction with other technologies (e.g., covers)
		Selection of pump size
		Selection between temporary and permanent pumping systems
	Flood potential	Need to increase berm height
		Need for diversion systems
		Applicability of diversion systems

TABLE 2-3. SUMMARY TABLE FOR PUMPING SYSTEMS

Response Option	Most Suitable Application	Criteria Precluding Selection	Criteria Affecting Selection	Associated Requirements	Total Cost
Temporary Pumps	Pumping small volumes at inaccessible sites over short periods of time	Large volumes of liquid being pumped on a regular basis	Volume of liquid to be pumped Frequency of pumping	Wastewater management (transport, storage, treatment)	$38-660/day
Permanent Pumps	Pumping large volumes over long periods of time	Small volumes of liquid being pumped infrequently	Volume of liquid to be pumped Frequency of pumping Power and security costs O&M costs	Wastewater management (transport, storage, treatment)	Variable - depends on pump size, capacity, and type

TABLE 2-4. SUMMARY TABLE FOR WASTEWATER MANAGEMENT OPTIONS

Response Option	Most Suitable Application	Criteria Precluding Selection	Criteria Affecting Selection	Associated Requirements	Total Cost
Truck transport	Occasional pumping of small volumes of wastewater Transport to an off-site treatment facility	None	Soil stability and load-bearing capacity	Recurring operations may require a cement pad with sump and pump	$2/mile (may be included in treatment fee)
Tank storage	In conjunction with a permanent pumping system	Inaccessibility of site to construction equipment	Soil stability and load-bearing capacity	Pumps, pipes and fittings, vapor release and level controls, valves, linings	Variable - depends on size, material, and associated equipment
Holding pond	Emergency containment of overflow (temporary measure)	High water table High soil permeability	If not implemented as part of removal action, must comply with RCRA standards	If used as a long-term measure, must install a liner and groundwater monitoring program	$55-125/hr (excavation only)

(continued)

TABLE 2-4. (continued)

Response Option	Most Suitable Application	Criteria Precluding Selection	Criteria Affecting Selection	Associated Requirements	Total Cost
Commercial wastewater treatment	Treatment of bulk wastewater	None	Proximity of treatment facility to site	Truck transportation	$25-175/ton
POTW *	POTW fees are less than commercial facility (e.g., a distant facility)	Wastewater components exceed POTW acceptance limits	Volume, composition, and concentration of wastewater Pretreatment requirements Access to a sewer system	Truck transportation Construction of a connection to a sewer system	Variable (depends on municipality requirements, wastewater characteristics, and sewer access charges)
Mobile treatment system	Pretreat wastewater prior to discharge to surface water or delivery to POTW	Treatment unit availability	Specific contaminants to be removed Required composition of treated effluent Water quality standards cannot be met	Adjacent waterway or connection to sewer system NPDES permit	$150-550/day (excludes demobilization/mobilization, disposal, utilities, and treatment chemicals)

* Publicly Owned Treatment Works

TABLE 2-5. SUMMARY TABLE FOR COVER SYSTEMS

Response Option	Most Suitable Application	Criteria Precluding Selection	Criteria Affecting Selection	Associated Requirements	Total Cost
Frame supported tension membrane structure	Long-term use Small lagoons	Smallest lagoon dimension exceeds 140 feet	Strong acids will corrode the structural frame Vapor, condensate, and air pollution control system will increase cost Unstable soils will not support construction equipment and load of structure 10 calendar days for delivery	Vapor, condensation, and air pollution control system required for volatile and toxic vapor controls	$8-19/ft^2
Prefabricated steel frame structures	Long-term use Small lagoons	Smallest lagoon dimension exceeds 200 feet	Strong acidic environment will corrode the structure Soil stability and load-bearing capacity 8-10 weeks for delivery	Vapor, condensation, and air pollution control system required for volatile and toxic vapors	$14-23/ft^2

(continued)

TABLE 2-5. (continued)

Response Option	Most Suitable Application	Criteria Precluding Selection	Criteria Affecting Selection	Associated Requirements	Total Cost
Air-supported structures	Long-term use Small to moderately large lagoons		Additional operating costs associated to keep the structure inflated 5 weeks - 4 months for delivery	Vapor, condensation, and air pollution control system required for volatile and toxic vapors	$3-10/ft^2
Floating covers	Moderate to long-term use	Subtantial debris on/in lagoon that cannot be removed	Cover material may swell due to content of lagoon, so that it has to be tested before reusing	Pumping system for rainwater removal (included in cost) Gas collection system for volatiles	$3-7/ft^2 (excluding gas collection)

TABLE 2-6. SUMMARY TABLE FOR SURFACE WATER CONTROLS

Response Option	Most Suitable Application	Criteria Precluding Selection	Criteria Affecting Selection	Associated Requirements	Total Cost
Ditches, diversions, and grassed waterways	Precipitation control (unconcentrated flow) Run-on control (unconcentrated flow)	Location in areas subject to high water flow and volumes may overwhelm diversion and interception capabilities of structures Drainage area of 5 acres or less	Must regrade if grade is >10% Capacity - design for 25-year storm Stabilization of channel required for channel slopes >5% Isolation/limited access - heavy machinery may be precluded by limited access to impoundment or instability of soils Source of construction materials: on-site reduces costs; off-site increases costs	Stabilized outlet: - Required for outfall - Sedimentation traps, chutes, and/or downpipes recommended	Variable

(continued)

TABLE 2-6. (continued)

Response Option	Most Suitable Application	Criteria Precluding Selection	Criteria Affecting Selection	Associated Requirements	Total Cost
Interceptor and diversion dikes and berms	Precipitation control (unconcentrated flow) Run-on control (unconcentrated flow)	Location in areas subject to high water flows and volumes will overwhelm diversion and interception capabilities of structures	Must regrade if grade is <10% Heavy machinery needed may be precluded by limited access to impoundment or soil stability Source of construction materials: on-site reduces costs; off-site increases costs	Stabilized outlet: - Required for outfall - Sedimentation traps, chutes, and/or downpipes recommended	Variable

(continued)

TABLE 2-6. (continued)

Response Option	Most Suitable Application	Criteria Precluding Selection	Criteria Affecting Selection	Associated Requirements	Total Cost
Terraces and benches	Precipitation control (concentrated flow) Run-on control (concentrated flow)	None	Must regrade if grade is >20% Capacity should be designed for 25-year storm Stabilization required where slopes become eroded or susceptible to differential settlement Heavy machinery required may be precluded by limited access to impoundment or by instability of soils	Feeder of water: ditches, diversions, grassed waterways, dikes, and/or berms may be used to collect water especially for wetter climates (not required if reverse benches and slope benches are used) Regrading may be necessary for installment	Variable

(continued)

TABLE 2-6. (continued)

Response Option	Most Suitable Application	Criteria Precluding Selection	Criteria Affecting Selection	Associated Requirements	Total Cost
Levees and floodwalls	Flooding/tide surges (concentrated flow) Run-on control (concentrated flow)	Insufficient construction space Where CWA * Section 404 permits cannot be obtained, option may be precluded	Swampy/unstable ground increases construction difficulty for heavy machinery Capacity design for 100-year flood Source of construction materials: on-site reduces costs; off-site increases costs	Water removal equipment needed to remove backflow	Variable

(continued)

* Clean Water Act

TABLE 2-6. (continued)

Response Option	Most Suitable Application	Criteria Precluding Selection	Criteria Affecting Selection	Associated Requirements	Total Cost
Dike and berm construction of impoundment wall	Overtopping due to precepitation Overflow from connecting lagoon or other system Run-on control	None	Degree of wall degradation: - Pumpdown and treatment is preferred option if wall too degraded - Heavy machinery may not be able to gain access due to wall weakness Vegetation present on wall may require more extensive repairs Source of construction materials: on-site reduces costs; off-site increases costs	Removal (pumping) of wastes to gain access to wall Surface run-on controls Use of liners Baffles or covers to control wave action	Variable

TABLE 2-7. SUMMARY TABLE FOR IMPOUNDMENT WALL IMPROVEMENTS

Response Option	Most Suitable Application	Criteria Precluding Selection	Criteria Affecting Selection	Associated Requirements	Total Cost
Impoundment dike and berm repair	Increase capacity through structural repair or design	None	Degree of wall degradation: - Pumpdown and treatment is preferred option if wall too degraded - Heavy machinery may not be able to gain access due to wall weakness Vegetation present on wall may require more extensive repairs Source of construction materials: on-site reduces costs; off-site increases costs	Removal pumping of wastes to gain access to wall Surface run-on control Use of liners Baffles or covers to control wave action	Variable

SECTION 3

PUMPING AND WASTEWATER MANAGEMENT

Pumping is commonly implemented as a stop-gap measure to prevent overtopping while a site is being studied for possible response action. Pumping may also be used to lower the level of wastewater in an impoundment to create a safe margin of freeboard prior to installing other types of temporary measures (e.g., covers, berm reconstruction). Pumping systems may be installed permanently during the time to the final action or brought on-site as needed.

Wastewater pumped from a lagoon must be managed so as to prevent degradation of the surrounding environment. The wastewater may be pumped to a tank truck for transport off-site to a commercially operated treatment facility or a Publicly Owned Treatment Works (POTW). It may first be pumped to a storage tank on-site prior to removal. Alternatively, a mobile treatment system could be brought on-site. Figure 3-1 illustrates these alternatives and the relationship between pumping, storage, and treatment options.

The following sections discuss factors affecting selection, installation, and costs of pumping systems as well as various wastewater management options. These sections also address the combinations of management options that may be implemented.

PUMPING SYSTEMS

Field implementation of lagoon level control options requires fitting the capabilities of a particular pump to the specific needs of the job.

Pump Types

Pump types may be divided into two major categories: (1) dynamic, in which energy is continuously added to increase the fluid velocity; and (2) displacement, in which energy is periodically added (Karassik et al., 1976). Dynamic pumps may be further subdivided into several varieties of centrifugal pumps. Displacement pumps are essentially divided into reciprocating and rotary types.

Dynamic centrifugal pumps have a wide range of capacities; flow rates range from 2 or 3 gpm up to 10,000 gpm (Perry and Chilton, 1973). The primary advantages are low initial cost and a simple design, which in turn means low maintenance and easy repair. These pumps are best suited for pumping large volumes against small heads (Cole-Parmer, 1982). They can handle liquid with large amounts of solids. Centrifugal pumps are limited in that they are not selfpriming, and therefore liquid must be added to the pump in order to start up the pumping action; they cannot pump dry.

Displacement rotary pumps are particulary useful for pumping viscous liquids, liquids of varying viscosities, and liquids with dissolved air or gas, and for low flow pumping. These pumps will handle any liquid that does not contain an abrasive material, and no priming is required (Perry and Chilton, 1973).

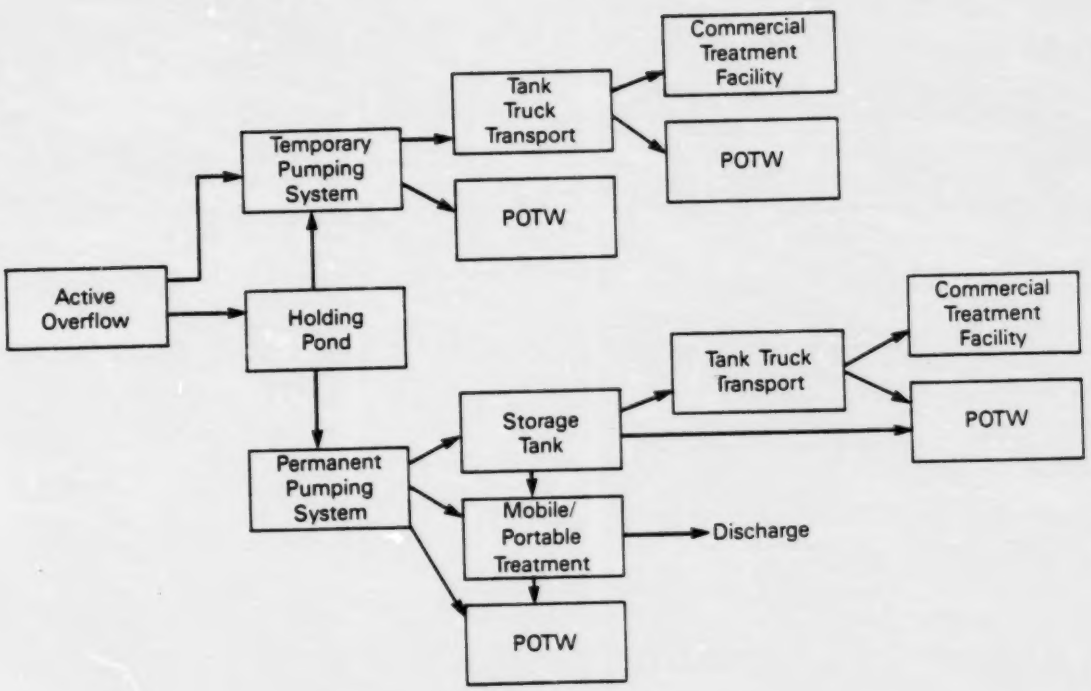


Figure 3-1. Flow Diagram of Pumping and Wastewater Management Options to Control Waste Lagoon Overtopping

There are three classes of displacement reciprocating pumps: piston, plunger, and diaphragm. Piston and plunger pumps both have the desirable characteristic of maintaining high volumetric efficiency at any desired flow rate (Karassik et al., 1976). Volumetric efficiency is the ratio of liquid actually pumped to that which theoretically should be moved based on piston displacement. (Perry and Chilton, 1973). In general, reciprocating pumps have the advantage of being able to deliver fluids against high pressures and operate with good efficiency over a wide range of operating conditions.

A major disadvantage of piston and plunger pumps is that they cannot be used with fluids that contain abrasive solids (Peters and Timmerhaus, 1980). However, diaphragm pumps employ a flexible membrane made of metal, rubber, or plastic, which eliminates exposure of seals, shafts, rotors, or packings to the liquid being pumped (Perry and Chilton, 1973). This is an important asset when equipment is required to handle toxic or hazardous liquids. The useful life of a diaphragm is more a function of the discharge head and the total number of times the diaphragm is flexed than the abrasiveness or viscosity of the liquid being pumped. In addition, diaphragm pumps can run dry indefinitely (Cole-Parmer, 1982).

Pump Selection

In selecting a pump, care must be taken to ensure reliable operation and control. Pump selection generally depends on the pumping capacity required and the materials to be pumped. The experience of pump manufacturers is often valuable in selecting the proper size and type of pump and motor.

Selecting a pump with enough capacity to move a fluid at the desired rate is defined as pump sizing. This process takes into consideration the static head that must be overcome to initially move the liquid, plus the friction head of the discharging piping system (Beck, 1984). Also considered are the suction and discharge heads that determine whether a pump can produce enough pressure to get the fluid where it needs to go. The capacity curves published by manufacturers are generally accurate only for water and may not apply to more volatile or more viscous liquids. Capacity decreases when gases become dissolved in the liquid or when viscosity increases. Pump sizing also depends on the volume of liquid to be pumped and the time period necessary to reduce the level. This must take into account anticipated volume additions to the lagoon (e.g., rainfall) and the frequency of such additions.

When dealing with hazardous wastes, the task of pump selection is further complicated by the presence of chemicals that could corrode or dissolve pump parts. Corrosive liquids have a low pH or a high chloride ion content and can rapidly destroy most metal pumps. Wetted parts should be plastic, rubber, or ceramic, or, if made of iron, should be alloyed with silicon and/or chromium (Beck, 1984). It is extremely important to check the chemical compatibility of seals with the fluid being pumped.

The presence of abrasive liquids also influences pump selection. Internal passages must have adequate dimensions or abrasive particles will damage parts that they rub against. Close internal clearances between stationary and moving parts is undesirable. Rubber and ceramic parts resist abrasive wear

better than metal parts (Perry and Chilton, 1973). Many manufacturers make abrasion-resistant models.

The pump is not the only critical component in a properly designed pump system. Other factors, such as pipe sizes and configurations, fittings, type of hose used, and nature of the substance being pumped, can determine to a large degree the efficiency of a pumping system.

Temporary Pumping Systems

Temporary pumping systems are most applicable to situations in which immediate measures are necessary to prevent lagoon overflow. Temporary systems are also applicable where there are infrequent pumping requirements prior to final response action at a site. Temporary pumps may be brought in to lower the lagoon level so that another temporary action such as a cover may be applied, or, if frequent liquid input to the lagoon exists, a permanent pumping system may be warranted.

A temporary pumping system consists of one or more pumps with associated hoses or piping to extract lagoon contents and move the liquid to a temporary storage or treatment system. Pumps on vacuum tank trucks may be used to fill the trucks directly from the lagoon.

The pumps require fuel or electricity to run. Regular inspections and monitoring are necessary during pump operation to ensure proper functioning and availability of fuel or power. In particular, centrifugal pumps must be monitored to prevent them from running dry. Suction hoses may require screens to prevent debris from entering the pump mechanism.

Permanent Pumping Systems

Permanent pumping systems are most applicable at sites where there is a frequent or continuous pumping need until a final response action is implemented. A permanent system consists of a pump, a pad, a covering structure, and hoses and piping. Fuel or electricity must be available to run the pump. For an automatic operation, liquid level controls must be installed in the lagoon to control pump action. For a large site, more than one pump system may be necessary.

Installation of an in-place pumping system would require either a direct outlet for the wastewater (such as a POTW connection) or an on-site storage system.

Specific design considerations for a permanent system are:

- Maximum inflow to lagoon from rainfall or run-on
- Start and stop levels of sensors that activate system
- Type and size of storage tank.

Once the pumping system has been installed, inspection and maintenance of pumping operations will be required. Because reliable level sensing devices to automatically activate pumps have been commercially available for a number

of years, a permanent system can operate on its own to prevent overtopping. However, operator inspections must still be conducted to ensure adequate pump function and storage facility operation. Installation of a permanent facility would also require a security system to protect against vandals. This may include perimeter fencing, lights, and even guards.

Costs

This section presents cost data for both permanent and temporary pumping system. These data are best estimates, and individual vendors should be contacted for specific costs. Annual costs for equipment maintenance and repairs may range from as low as 2 percent of the equipment costs if service demands are light to 20 percent for cases in which there are severe operating demands (Peters and Timmerhaus, 1980). Operating costs are determined by the size of the pump (i.e., horsepower) and the number of hours of operation.

Power costs for a pump are determined using the following equations:

(1) Power consumption $= \frac{bhp}{Em}$

bhp = brake horsepower
Em = efficiency

(2) Power cost $= \frac{bhp}{Em}$ (0.7457 kw/hp) (cost/kwH) (operating hours)

kwh = kilowatt-hour
hp = horsepower

Power costs for 10, 50, and 100 bhp pumps are $932, $4,600, and $9,320, respectively. These costs are based on an 80 percent operating efficiency, 1,000 hours of operation, and an electricity cost of $0.10/kilowatt-hour.

The following sections present cost data for permanent and temporary pumps.

Permanent Pumps--

Table 3-1 presents costs for carbon steel and stainless steel reciprocating, rotary, and centrifugal pumps. These costs were adjusted using the Chemical Engineering Plant Cost Index for June 1984. Installation costs for permanent pumps range from 30 to 60 percent of the cost of the pumps themselves (Peters and Timmerhaus, 1980).

As shown in Table 3-1, the total costs of installed pumping systems range as follows:

- 10 gpm: $1,600 to $18,100
- 100 gpm: $3,500 to $44,800
- 1000 gpm: $5,700 to $213,200.

TABLE 3-1. PUMP COSTS

Type	Capacity (gpm)	Material of Construction[1]	Equipment Cost[2]	Installation Cost[3]	Total Cost
Reciprocating	10	CS	$ 8,400	$ 3,800	$ 12,200
		SS	12,500	5,600	18,100
	100	CS	20,900	9,400	30,300
		SS	30,900	13,900	44,800
	1000	CS	99,300	44,700	174,000
		SS	147,000	66,200	213,200
Rotary	10	CS	1,100	500	1,600
		SS	1,600	700	2,300
	100	CS	3,700	1,700	5,400
		SS	5,400	2,400	7,800
	1000	CS	9,400	4,200	13,600
		SS	14,000	6,300	20,300
Centrifugal	10	CS	1,800	800	2,600
		SS	2,100	900	3,000
	100	CS	2,400	1,100	3,500
		SS	2,800	1,300	4,100
	1000	CS	3,900	1,800	5,700
		SS	4,700	2,100	6,800

1. CS = carbon steel, SS = stainless steel

2. Costs adjusted to 1984 costs.

3. Installation costs range from 30 to 60 percent of equipment costs (Peters and Timmerhaus, 1980); a median value of 45 percent is used.

Source: Corripio, Chrien, and Evans, 1982

Temporary Pumps--

Table 3-2 presents 1981 rental costs for pumps and hoses for temporary systems. These data were compiled from vendor information.

WASTEWATER MANAGEMENT

Wastewater pumped from an impoundment can be directed through several pathways prior to treatment. It can be pumped to a tank storage facility present on-site for later transport to an off-site treatment facility. Pumping can be directed to a tank truck, which will deliver the wastewater to a POTW or commercially-owned treatment facility. A mobile treatment facility can be brought on-site for preliminary treatment of wastewater so that it is acceptable for POTW facilities or for discharge into nearby waterways. The wastewater may be discharged directly to a POTW, provided that sewer connections are available and that the liquids are acceptable for the POTW. Finally, where a lagoon is actively overflowing, a temporary on-site holding pond may be constructed to contain the liquid until further measures can be taken. These options are presented in Figure 3-1, at the beginning of this section.

The following sections describe various transportation, storage, and treatment options for managing wastewater pumped from a surface impoundment.

Truck Transport

Truck transport may be the most feasible alternative for removal of wastewater. Vacuum tank trucks are generally equipped with pumps, which may be used to pump the lagoon contents directly. The subgrade at the site must be capable of supporting a cement pad equipped with a sump for loading operations when this would occur frequently. The truck would park on the pad while being filled and any spills that might occur would be collected in the sump. The wastewater would be taken to a commercial treatment/disposal facility or to a POTW if it meets the POTW limitations.

A general rule of thumb for transportation costs is approximately $2/mile. The transportation fee may be incorporated into the commercial facility's fee for wastewater treatment or disposal.

Tank Storage

The installation of an on-site storage facility is generally necessary for a permanent pump system. Tanks are constructed of a variety of materials, including carbon steel, other metals, and plastics. The choice of material depends on the chemical characteristics of wastewater being contained. Carbon steel is most frequently used. Liners or special coatings may be necessary to improve corrosion resistance and compatibility of wastes and tank materials. Specific information on the compatibility of various substances can be obtained from the draft Permit Guidance Manual on Tanks (Senger and Fred C. Hart Associates, 1981) or the Chemical Engineers Handbook (Perry and Chilton, 1973).

Auxiliary equipment that supports operation of the tank includes foundations; pressure controls; overfilling controls; and pumps, piping, and fit-

TABLE 3-2. RENTAL COSTS FOR PUMPS AND HOSES

PUMPS	COSTS
Pneumatic Powered	
2" Double diaphragm	$ 38.50/day
2" Double diaphragm stainless	75.00/day
Submersible Electric Powered	
2" Submersible	38.50/day
4" Submersible	220.00/day
Acid	
3" x 2" Butyl lined acid pump	528/day
3" x 2" Self priming acid and chemical pump	126.50/day
Engine Powered, Trailer or Skid Mounted (Centrifugal)	
1-1/2" Centrifugal/gear	30.00/day
2-1/2" Sludge submersible (hydraulic)	44.00/day
4" Submersible (hyraulic)	165.00/day
3" Trash	220.00/day

HOSES	COSTS[1]
Air	
1" x 50'	$ 99.00/month
2" x 25'	99.00/month
Water	
1" x 50'	58.50/month
2" x 50'	148.50/month
2-1/2" x 50'	180.00/month
Chemical	
1" x 50'	148.50/month
1-1/2" x 25'	198.00/month

[1] Costs for hoses take into account the different hose materials available based on the type of medium to be pumped.

Source: Data compiled from vendor files.

tings. Specific standards for designing foundations vary with site conditions. Appropriate foundations are especially important when the facility is located in earthquake zones, marshy areas, or otherwise unstable zones. Testing should be done to verify that the subsurface can withstand the weight of the tank and its contents when full (Battelle Columbus Laboratory, 1983).

One of the most effective means of preventing overfilling in a tank is through the use of a liquid-level measuring device connected to an alarm or automatic feed cut-off system; this system would have to operate in conjunction with the lagoon liquid level control system running the pump. Pressure releases may be necessary in certain situations; vapors released during this process may need to be collected and undergo a treatment process. Piping, pumps, and valves are an integral part of a tank system, and some analysis must be performed to ensure that the size and configuration are capable of performing with a low risk of failure (JRB Associates, 1982a).

Inspections of a tank and its auxiliary equipment must be conducted on a routine basis (i.e., weekly) to ensure that the system is in good working order and to prevent uncontrolled leaks.

As described above, storage facilities involve a wide variety of configurations, materials, and operating conditions. Study grade estimates of costs generally have an accuracy of ± 30 percent. Such cost estimates can be made for tanks of various materials of construction using a method developed by Corripio, Chrien, and Evans (1982). This method determines cost as a function of required storage volume and location of tank construction. Using this method, the cost estimation formulas for carbon steel tanks are:

(1) Base cost (C_B) for shop-fabricated tanks (1979 dollars)

$$C_B = \exp [2.331 + 1.3673(\ln V) - 0.063088(\ln V)^2]$$

V = volume in gallons
Lower limit = 21,000 gallons
Upper limit = 11,000,000 gallons

(2) Base cost (C_B) for field-erected tanks (1979 dollars)

$$C_B = \exp [11.362 - 0.6104(\ln V) + 0.045355 (\ln V)^2]$$

V = volume in gallons
Lower limit = 21,000 gallons
Upper limit = 11,000,000 gallons

The cost formula for field-erected tanks includes costs for ladders and platforms, but does not include foundations or other installation materials such as piping. The cost formula for shop-fabricated tanks does not include any installation materials (JRB Associates, 1982a). Both of these cost estimates are based on dollar values in the first quarter of 1979 and should be adjusted to present dollar values using the Chemical Engineering Plant Cost Index.

Costs defined by the estimates presented previously are for carbon steel tanks. The base cost for several of the most commonly used capacities are presented below:

Capacity (gal)	Base Cost (C_B)	Installation Cost	Total Cost
1,000	$ 8,200	$ 3,700	$ 11,900
10,000	18,300	$ 8,200	$ 26,500
100,000	39,600	$ 17,800	$ 57,400
1,100,000	136,600	$ 61,500	$198,100

These costs have been adjusted to 1984 prices using the Chemical Engineering Plant Cost Index for June 1984. Current costs for tanks constructed of other materials can be obtained by multiplying the base cost (C_B) by the appropriate material of construction cost factor (F_M). Cost factors for various tank construction materials are presented in Table 3-3 and they do not require adjustment to current prices. Tank installation costs range from 30 to 60 percent of the tank cost (Peters and Timmerhaus, 1980); an average installation cost of 45 percent of the base cost was used to generate the data presented above.

Auxiliary equipment would include piping systems, linings and coatings, valves, pressure relief, and level control. Price ranges for pipes and fittings are $30 to $400 (1984) for carbon steel and $45 to $1,250 (1984) for stainless steel. Costs for linings and coatings, 5 to 7 mils thick, factory installed, can range from $6/ft^2 (epoxy/polyvinyl chloride) to $30/ft^2 (fluoroplastics). The 1982 costs for venting or pressure relief systems ranged from $250 to $3,000. Valve costs (1984) range from $300 to $7,000 for stainless steel and $230 to $4,100 for cast steel. Level controls are highly variable in price. Estimated costs for various level indicator and control systems are presented in Table 3-4.

On-Site Holding Pond

On-site holding ponds may have a function as a short-term emergency response geared toward immediate control of liquids overtopping a surface impoundment. Site conditions such as high soil permeability and proximity of groundwater to the surface should preclude this response mechanism where environmental risk is increased; this must be evaluated on a site by site basis. Once the overflow is controlled, other means should be sought to manage the wastewater generated and to prevent further overflows.

For a temporary holding pond, construction equipment is brought to the site to excavate a pond to contain the liquid.

The use of a holding pond for other than temporary storage is limited. In instances in which holding basins are to be used for long-term storage, these structures would need to meet Resource Conservation and Recovery Act (RCRA) standards, which provide for installation of a liner system and a groundwater monitoring program. This would severely limit the cost-effectiveness of this option.

TABLE 3-3. MATERIAL OF CONSTRUCTION COST FACTORS FOR STORAGE TANKS

Materials of Construction	Cost Factor (F_M)
Carbon steel	1.0
Stainless steel 316	2.7
Stainless steel 304	2.4
Stainless steel 347	)
Nickel	3.5
Monel	3.3
Inconel	3.8
Zirconium	11.0
Titanium	11.0
Brick-and-rubber or brick-and-polyester-lined steel	2.75
Rubber- or lead-lined steel	1.9
Polyester, fiberglass-reinforced	0.32
Aluminum	2.7
Copper	2.3
Concrete	0.55

Source: JRB Associates, 1982a

TABLE 3-4. ESTIMATED COSTS OF LIQUID LEVEL INDICATOR AND CONTROL SYSTEMS

Description	1982 Cost* ($)
Standard level gauge (float, type, guide wires, ground reading level indicator, stainless steel construction)	600
High level switch assembly	175
**Annuciator panel (alarm) (for 6 tanks, two alarm points each)	2,800-3,000
Backup system (displacement system)	300
Level control (top mounted, single actuated)	197
Electric actuated ball valve	
- 1 inch	188
- 2 inch	375
- 3 inch	688
- 4 inch	1,025
Electric actuator (for above valve)	300-470

* Excludes installation
**Annunciator = electrically controlled signal board or indicator

Source: JRB Associates, 1982a

Commercial Treatment Facilities

A variety of wastewater treatment methods exist at commercial, RCRA-approved facilities. Fees for bulk wastewater loads vary with the type and quantity of waste. The fee generally includes a disposal fee and may or may not incorporate a transportation fee. The costs for five common treatment and destruction technologies are presented in Table 3-5. All costs include disposal of residues remaining after waste has been processed.

Off-Site Publicly Owned Treatment Works (POTWs)

POTWs may offer an alternative to commercially-owned facilities for treating wastewater. The major factors that determine the feasibility of this option are access to a sewer system and the characteristics of the waste. EPA regulators require that only "compatible" wastes be discharged to POTWs. Pretreatment regulations have been promulgated by EPA for most major industries. Municipalities may further control the wastes accepted through their own ordinances. This option is not feasible where the lagoon wastewater exceeds specific POTW limits. Pretreatment of the liquid to meet POTW limitations is feasible but is not likely to be cost-effective when compared to the use of commercial treatment/disposal facilities.

POTWs may also have flow rate or volume limits. Such limits would affect the ability to discharge waste liquids within a reasonable period of time.

The costs of this wastewater management option are largely based on POTW user fees. Both volume and strength of the waste are considered in assessing user charges. The two most common parameters of waste strength are biological oxygen demand (BOD) and suspended solids (SS) (Ashton and Walker, 1978). User charge systems in areas where industrial effluents do not constitute a major portion of wastewater are structured such that one rate is established for wastes of normal domestic strength and another higher rate for strong waste discharges. It is widely accepted practice to consider normal domestic sewage strength to be approximately 250 ppm for both BOD and SS (Ashton and Walker, 1978). In smaller communities, waste treatment plants are specifically designed to operate most efficiently with incoming waste flows having strengths of approximately 250 ppm.

POTWs in areas where industry is prevalent may use higher BOD and SS values to define normal domestic sewage strength. Strong waste discharges are assessed an additional surcharge, and the rates vary from muncipality to municipality. Clearly, the costs associated with POTWs are highly site-specific. Ideally, the local POTW should be contacted and rates obtained as part of a general cost analysis to determine the most cost-effective wastewater management option. An additional cost associated with using a POTW is the connection fee that is levied any time a connection is made or an existing connection to a sewer system is increased. Additional costs may be incurred when a sewer connection must be constructed.

TABLE 3-5. COST ESTIMATES FOR TREATING WASTEWATER

Treatment Technology	Cost[1] ($/Ton)
Neutralization/precipitation Including screening, sedimentation, flotation	30-150
Aqueous organic treatment Including sedimentation, filtration, steam stripping, carbon absorption, and biological treatment	30-60
Chemical oxidation/reduction Includes neutralization, precipitation, solid/liquid separation	50-175
Solvent recycling Includes distillation, steam stripping, extraction	50-100
Oil/water separation Includes sedimentation, emulsion breaking	25-125

1. All costs include disposal in California Class 1 (hazardous waste) landfills of the residue remaining after the waste has been processed.

Source: Office of Appropriate Technology, 1981

Mobile/Portable Treatment Systems

Mobile/portable treatment systems may need to be brought on-site to pretreat wastewater prior to delivery to a POTW. Wastewater treated on-site may also be discharged directly from the site to a surface water body if it meets water quality standards specified within a National Pollutant Discharge Elimination System (NPDES) permit obtained specifically for the job. The effectiveness of a mobile treatment unit is determined by its ability to satisfactorily treat the wastewater.

The type of treatment depends on the overall chemical composition of the waste, the specific contaminants to be removed, and the required composition of treated effluent. Mobile systems capable of flocculation, sedimentation, and filtration of suspended solids from wastewater prior to the removal of hazardous materials have been developed. The clarified liquid can then be directed through carbon adsorption columns for removal of organic contaminants. Carbon adsorption is well suited for contaminated wastewater because it is capable of removing complex mixtures of organic contaminants, however, carbon adsorption may not be suitable for all organics.

Table 3-6 presents costs for mobile treatment equipment excluding the cost of materials, treatment chemicals, mobilization and demobilization, utilities, and disposal. The costs for these items are highly variable and depend on site location, treatment needs, and distance from available equipment. It should be noted that these costs may have a significant impact on the cost of this alternative.

SUMMARY

Wastewater removed from surface impoundments to prevent overtopping can follow several treatment options. In most cases, mobile pumps will be used to control the level of wastewater. This includes truck pumps associated with vacuum tank trucks. At some point, the size of the surface impoundment and volume of water being pumped is large enough that a stationary pump system becomes more cost-effective.

A variety of options exist for handling the liquid pumped from the surface impoundment. Liquids could be pumped to a storage tank on-site or a tank truck may be used to transport wastewater to an off-site POTW or commercially operated treatment facility. Mobile treatment units may be brought on-site to pretreat wastewater in order to make it acceptable for a POTW. Wastewater can also be discharged directly from the site to a surface water body if it meets water quality standards specified within an NPDES permit. Finally, the liquid may be discharged directly to a POTW provided that sewer connections are available and that the composition of the liquid is acceptable for the POTW.

TABLE 3-6. SELECTED MOBILE TREATMENT COSTS

Treatment Equipment	Cost ($/day)
Activated carbon treatment system, mobile, three stage	550
Activated carbon treatment system, skid mounted, two stage	450
Ion exchange treatment system, mobile	400
Fluid/particulate filters	150

Source: Data compiled from vendor information.

SECTION 4

LAGOON COVER SYSTEMS

Waste lagoons may be covered in order to prevent precipitation accumulation that may cause the impoundment to overflow. There are a variety of cover systems commercially available to protect lagoons from precipitation. These systems include:

- Frame-supported tension membrane structures
- Prefabricated steel frame structures
- Air-supported structures
- Floating covers.

Frame-supported tension membrane structures have been used in aviation (portable aircraft hangers), manufacturing (portable factories), and mining (refinery plant covers). Prefabricated steel frame structures have been used for warehouses. Air-supported structures have been used to cover recreational areas (tennis courts), bulk storage facilities, and sewage treatment facilities. Floating covers have been used over potable water reservoirs, chemical treatment ponds, and toxic waste lagoons.

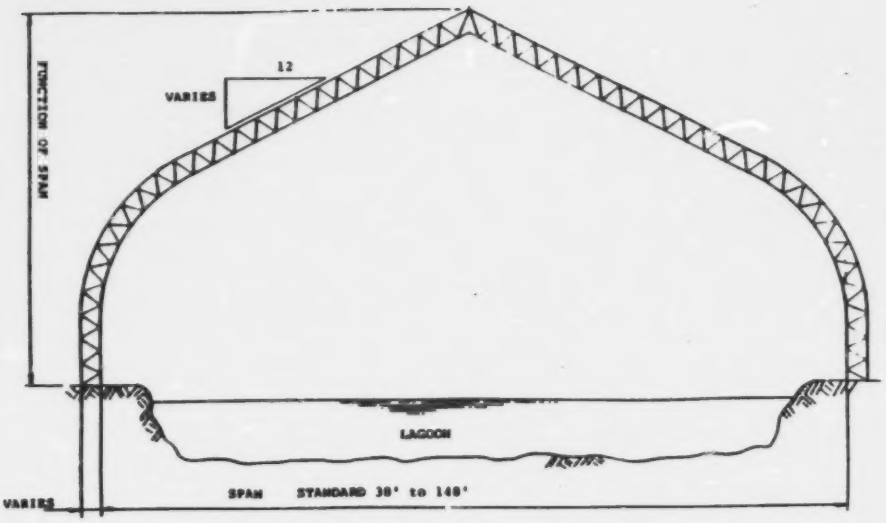
Each of these technologies is described in the following sections. Each section presents features of the various technologies and the limitations associated with each system. Specifically, these systems are examined based on system design, materials of construction, installation techniques, auxiliary systems, special factors, and total costs. Appendix A provides a list of the manufacturers presented in this section, their addresses, and telephone numbers.

FRAME-SUPPORTED TENSION MEMBRANE STRUCTURES

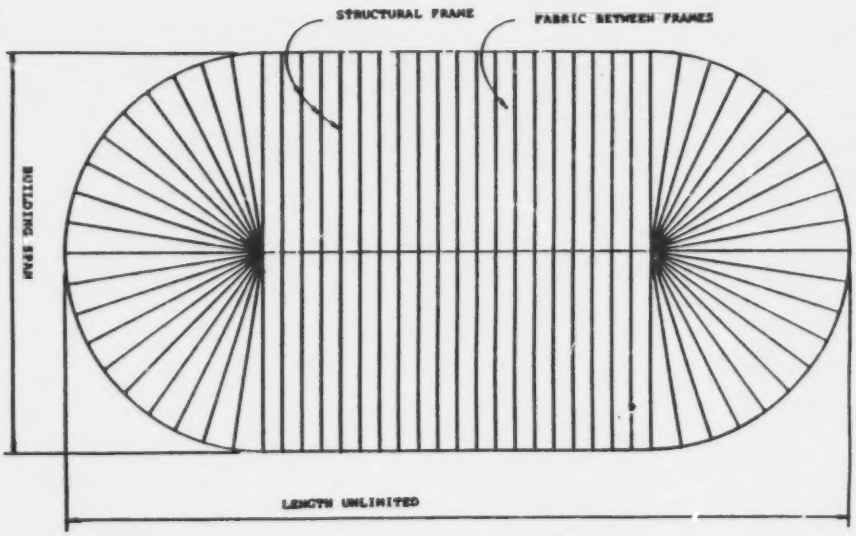
Frame-supported tension membrane structures provide an efficient and stable building with a free span coverage of a site. These structures consist of fabric panels tensioned between specially designed arches and are available commercially from a number of manufacturers.

System Design

Sprung Instant Structures, Inc., has a frame-supported tension membrane structure that is constructed from extruded aluminum arches integrally connected to an all-weather outer membrane of polyvinyl chloride (PVC) coated polyester scrim, which is treated with inhibitors to prevent degradation from ultraviolet (UV) radiation from the sun. Concrete support columns are erected at the base of each arch. Figure 4-1 illustrates this structural system. The structure can be engineered to withstand snow and wind loadings up to 50 lbs/ft^2 and 140 mph, respectively. Standard structures are available in modular unit widths of 30, 40, 50, 60, 88.5, 120, and 140 feet and ranging from 10 to 15 feet in length (A.J. Kuster, Sprung Instant Structures, Inc., personal communication, 1984). These modular units span any length desired, but are limited in application by the width dimension.



Typical Cross Section (Sprung Instant Structures)



Building Plan (Sprung Instant Structures)

Reprinted courtesy of Sprung Instant Structures, Inc., Balavia, IL.

Figure 4-1. Frame-Supported Tension Membrane Structures

Another type of frame-supported tension membrane structure is manufactured by Seaman Building Systems and is known as Portomod. Figure 4-2 illustrates the typical cross section of the Portomod. This structure uses a structural steel space frame supporting a Shelter-Rite roof. The sidewall membrane material consists of tire cord strength polyester coated with proprietary vinyl compounds to provide stress- and weather-resistant qualities. This structure can withstand hurricane force winds up to 120 mph, and can be designed to withstand snow loads of up to 50 lbs/ft^2. The freeflowing curvature of Seaman structures causes the snow to slide off rather than build up. The modular design of the Portomod unit uses steel trusses and a sectionalized roof membrane to span widths up to 124 feet with unlimited length (J. Bates, Seaman Building Systems, personal communication, 1984).

Both of the above designs protect a lagoon from further liquid additions from precipitation. However, both also limit ventilation of the lagoon, thus promoting the buildup of evaporated materials that may be toxic or explosive. As described later in this section, auxiliary control systems or design modifications can reduce or eliminate this problem. Where an explosion potential exists, other cover systems (such as floating covers) may be more appropriate.

Materials of Construction

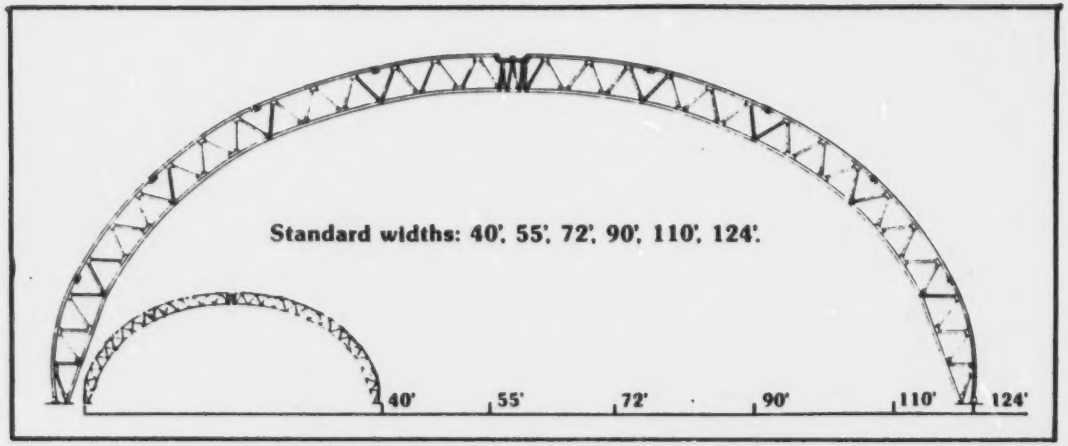
The frame for the Sprung Instant Structure is made of aluminum and the covering membrane is a PVC coated polyester scrim. Seaman Corporation uses a frame made of galvanized steel, and the membrane material is PVC-coated tire cord strength polyester. (J. Bates, Seaman Building Systems, personal communication, 1984). The contents of the lagoon should be analyzed and the manufacturers consulted regarding materials/waste compatibility before final selection of the frame type and membrane material.

Installation

The Sprung Instant Structure can be erected on any firm surface that is reasonably flat. No surface preparation foundations are required for structures up to 60 feet wide. Anchors secure the arches to their support column. Special anchor systems are needed for areas consisting of sand or peat. Large structures require concrete footings under each beam. Anchorage is obtained with two drift pins at each column base plate. Site preparation may be necessary to construct a supporting earthwork for the anchoring system (A.J. Kuster, Sprung Instant Structures, Inc., personal communication, 1984).

The structure consists of modular components that can be packaged in bundles and transported to the site. Delivery can be obtained within 10 calendar days after ordering. On-site, the components are bolted together to form the frame, and erected using a crane. The arches are then secured with anchor bolts (A.J. Kuster, Sprung Instant Structures Inc., personal communication, 1984).

Simple foundation piers with anchor bolts are all that is required to secure a Portomod structure without sidewalls and doors. If sidewalls and



Reprinted courtesy of Seaman Building Systems, Sarasota, FL.

Figure 4-2. Typical Cross-Section of the Portomod Structure (Seaman Building Systems)

doors are required, a concrete grade beam between each support pier is necessary for their installation. The lightweight modular components are manufactured in shapes and sizes that can be nested and bolted into packaged bundles that are quickly loaded, off-loaded, sorted, and installed. Fastening devices have been kept to a minimum. The lightweight Shelter-Rite roof segments are all prefolded and rolled on steel pipes for fast, safe handling. When pulled out and tensioned to the steel arches, these segments cover thousands of square feet at a time. A long boom crane is required to erect large structures (J. Bates, Seaman Building Systems, personal communication, 1984). Approximately 2,000 ft^2 can be erected in an 8-hour day.

To install either structure, the site must be accessible to the necessary construction equipment and sufficiently stable to withstand the heavy loads of cranes, backhoes, and concrete trucks as well as the weight of the final structure.

Auxiliary Systems

Auxiliary systems for frame-supported tension membrane structures generally involve the management of vapor and condensate buildup from evaporation of lagoon contacts. These structures may be contructed to provide adequate ventilation, thus preventing the buildup of volatile vapors within the structure. This is accomplished by omitting fabric in the vertical walls to allow sufficient air passage and eliminate stagnant pockets of volatile vapors (Mason & Hanger, 1983). It may also be necessary to install air pollution control devices such as carbon adsorption units attached to vents to control toxic vapors. A special catchment around the base of the structure may also be necessary to control condensate that can flow down the walls and onto the ground. Such a catchment would return the condensate to the lagoon. The manufacturer can provide the engineering designs of auxiliary systems upon request.

Special Factors

The life expectancy of the support beams for both systems is indefinite while the fabric material in the Sprung Instant Structures has a life expectancy of 10 to 12 years. These structures require very little monitoring and maintenance, are reusable, and can be dismantled in half the time required for erection (A.J. Kuster, Sprung Instant Structures Inc., personal communication, 1984). The oldest Seaman systems structure is seventeen years old and with the advent of Tedlar® top finish, fabric should easily last 15 to 20 years (J. Bates, Seaman Building Systems, personal communication, 1984).

Upon dismantling, all of the components can be reused. However, decontamination of the structure would be required prior to reuse of the structure at a new site.

The structure and auxiliary devices require monitoring and maintenance. The frame and fabric must be periodically examined for corrosion. Fabric panels may be removed and replaced if necessary. Condensate controls, fire control systems (if utilized), and ventilation (vapor) controls must also be examined on a regular basis. Air pollution control devices must be tested to determine their effectiveness.

Costs

The cost of a Sprung Instant Structure varies from $\$10/ft^2$ to $\$17/ft^2$ for a 30-foot span and 120-foot span, respectively. The cost for erection of the structure is approximately $\$2/ft^2$. The cost of site preparation and foundations for the structure would be approximately $\$1/ft^2$. Thus, the total cost of this structure ranges from \$12 to $\$19/ft^2$ depending on the system (Mason & Hanger, 1983).

The material cost of the Seaman (Portomod) structure ranges from \$6 to $\$12/ft^2$ for a 40-foot span and 124-foot span, respectively. The cost of erection is approximately $\$1/ft^2$ with foundations and site preparation costs ranging from \$1 to $\$2.50/ft^2$. Therefore, the total cost of the structure ranges from \$8 to $\$14.50/ft^2$ depending on the system.

Additional costs would be incurred if an air pollution control device or condensate control system was used. These costs would vary according to the extent of the system and the manufacturers (J. Bates, Seaman Building Systems, personal communication, 1984).

Summary

Frame-supported tension membrane structures are available at total costs ranging from $\$8/ft^2$ to $\$19/ft^2$. There are limited operational costs associated with this cover structure unless special control systems are required.

These cover structures cannot be used if the smallest lagoon dimension is greater than 140 feet or if the soil conditions are inadequate to support the load of the structure, and/or the construction equipment. The site must also be easily accessible in order to erect the structure, with sufficient room to bring in and operate a crane. The frame is susceptible to attack by strong acids and may require treatment with special coatings in an acidic environment.

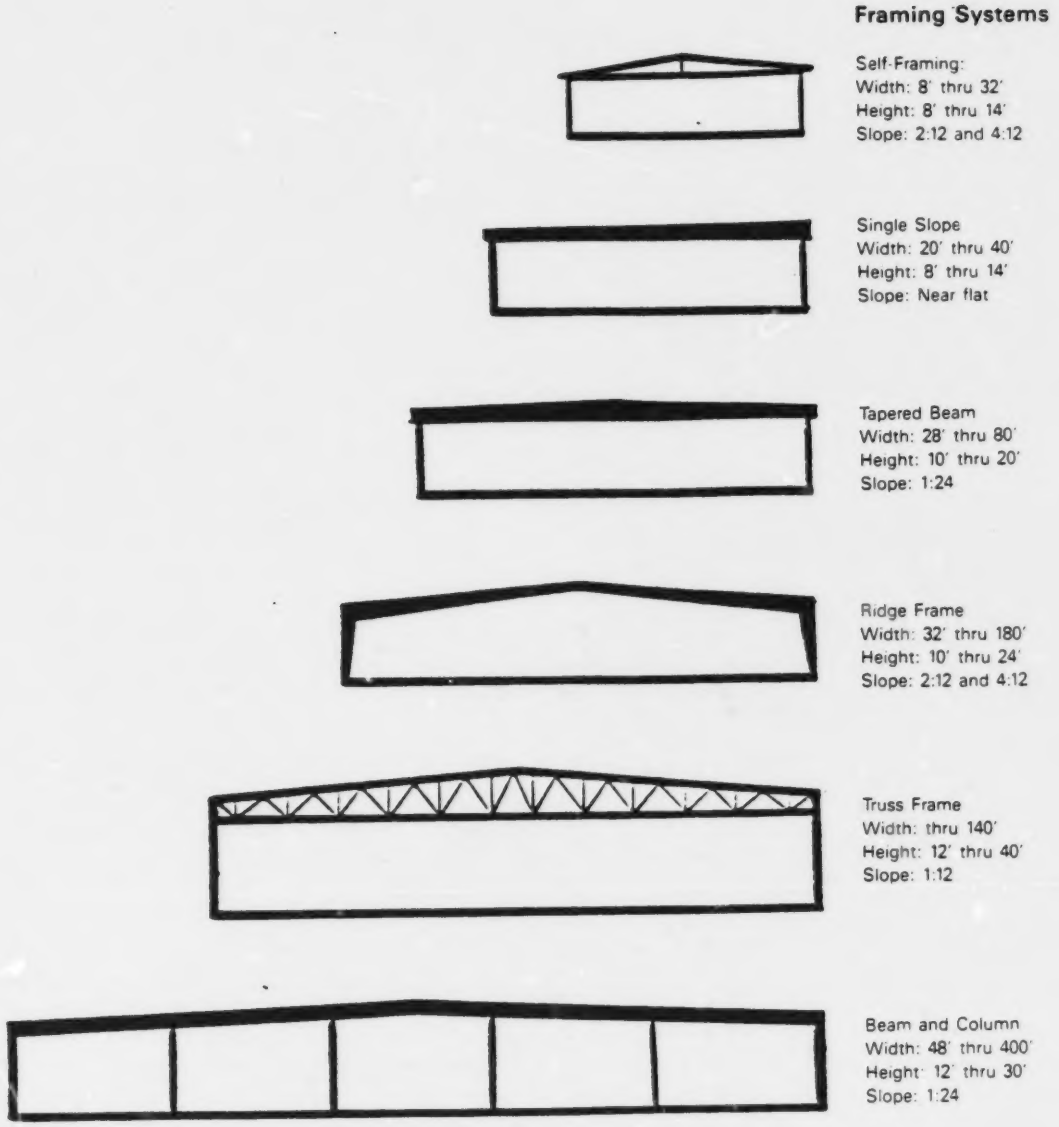
In general, this option is not feasible for short-term usage. However, this type of structure is reusable and can be decontaminated, thus rendering this option more cost-effective through reuse at other sites.

PREFABRICATED STEEL FRAME BUILDINGS

Prefabricated steel frame buildings may also be used to cover lagoons. There are many manufacturers of steel framed buildings and various types of structures. Figure 4-3 illustrates several building systems that are available, with the rigid frame system being one of the more common and most practical to use over moderately sized lagoons.

System Design

Six types of building systems are illustrated in Figure 4-2: self-framing, single slope, tapered beam, rigid frame, truss frame, and beam and column. The application of these frame covers is limited by their dimensions, provided in Figure 4-3, as well as their anchoring and support systems. The



Source: Mason & Hanger, 1983

Figure 4-3. Prefabricated Steel Frame Structures

self-framing structure is structurally self-supported and it requires minimum foundation or slab support. The single slope or tapered beam framing structure is designed with a very stiff crossbeam that eliminates most of the lateral thrust on the foundations.

These systems as well as the rigid frame, truss frame, and beam and columns systems are manufactured in 20 to 30 foot column spacing depending on the manufacturer. The rigid frame system can span up to approximately 180 feet (Mason & Hanger, 1983). Shenango Steel Building, Inc., has buildings that can span 100 feet with unlimited length; Butler Buildings, Inc., has buildings that can span 200 feet, with no length limitations.

These structures can be designed to withstand live loads up to 50 lb/ft^2 and wind loads up to 70 mph.

Associated with this type of system are very high lateral forces at the foundations (T. Clark, Shenango Buildings, Inc., personal communication, 1984). These forces are sometimes carried by tension tie rods between the column bases. The truss frame system is a practical system for longer spans because it has a smaller lateral thrust reaction at the foundation than the rigid frame system. Beam and column systems are used to cover large areas. However, this system requires that intermediate columns be installed; such a system is not practical to use as a lagoon cover system.

Materials of Construction

The roof cover for steel frame buildings consists of a metal skin attached to longitudinal purlins; the walls consist of a metal skin over girts. Normally, the walls and roof are made of painted steel; where corrosion is a problem, galvanized steel or aluminum can be used or a special protective coating can be applied. The structural framing system is usually aluminized steel and may be coated with aluminum silicon or another coating to improve compatibility with lagoon contents (Mason & Hanger, 1983).

Installation

Like the frame-supported tension membrane structures, the modular components of prefabricated steel frame buildings are transported to the site with delivery in 8 to 10 weeks after ordering. On-site, the components are bolted together to form a frame, erected using a crane, and tied down to the surrounding soil with anchor bolts. A long-boom crane or a helicopter may be required to erect a large structure (B. Hamilton, Butler Buildings, Inc., personal communication, 1984). A foundation consisting of either a concrete grade beam or concrete piers must be constructed prior to installation. The site must be easily accessible for construction equipment, and the soil conditions must be such to withstand the equipment and building loads.

Auxiliary Equipment

The walls of steel-framed structures can be eliminated where the requirement is only to prevent precipitation from entering the lagoon. Ventilators can be added in the roof of structures that are totally enclosed to allow

vapor buildup to escape (Mason & Hanger, 1983). Air pollution control devices such as carbon adsorption units may be necessary to control toxic vapors.

In addition, special condensate control measures may be necessary to avoid contamination of the soil surrounding the lagoon through condensation of waste vapors and their run-off along the structure. Fire or explosion control systems may be necessary where lagoons have ignitable contents or explosive vapors. All of the above-mentioned auxiliary systems can be designed by the manufacturer for specific site conditions.

Special Factors

The steel frame structures are totally bolted together for field erection. They can be dismantled, decontaminated, then reused at a new site. The span of the structure cannot be changed without redesign; however, the length can be reduced or increased (Mason & Hanger, 1983).

Costs

The cost of materials for prefabricated steel frame structures is approximately $\$5/ft^2$. With erection foundation cost added, the total cost can range from \$14 to $\$20/ft^2$ depending on the site and structure size (T. Clark, Shenango Steel Buildings, Inc., personal communication, 1984). For Butler Buildings, Inc., the total cost of a structure ranges from $\$16/ft^2$ for an uncoated small structure to $\$23/ft^2$ for a coated large structure. Installation and total costs can be higher if a helicopter is needed to erect the structure or special coatings are required to improve compatibility with lagoon contents (B. Hamilton, Butler Buildings, Inc., personal communication, 1984).

Summary

The total costs of a prefabricated steel frame structure to cover a lagoon varies from \$14 to $\$23/ft^2$ depending on the site, design of the structure, coating required, and manufacturer. In most cases, a special coating may also be required to increase the longevity of the structure. The structure can be decontaminated, dismantled, and reused. This structure cannot be used if the smallest lagoon dimension is greater than 200 feet. As with other structures, it is necessary to determine the stability of the soil to withstand the loading of the building and construction equipment.

In general, the high costs of a prefabricated steel frame structure make this control measure infeasible unless it can be reused at other sites.

AIR-SUPPORTED STRUCTURES

Air-supported structures have been used for warehouses, construction shelters, and covers for recreational facilities, sewage treatment facilities, and landfills. This type of structure is a totally free span structure that maintains stability in space and resistance to loads through a pressure differential between the interior and exterior of the structure. This method of support leaves the interior free of poles, pillars, or other support devices

that would be impractical to erect on a lagoon (R. Morrison, Thermo-Flex Inc., personal communication, 1984).

System Design

An air-supported structure consists of a fabric supported by anchored cables and inflated by blowers that run continuously. The support cables are radially attached within the fabric to relieve stress on the fabric by transferring the load from the fabric to the cables and ultimately to the anchorage system. Most systems are designed to withstand wind speeds of 80 to 120 mph and up to 10 inches of heavy, wet snow or 50 lb/ft^2 (R. Morrison, Thermo-Flex Inc., personal communication, 1984). Figure 4-4 illustrates the structural components of an air-supported structure.

There are a variety of methods available to anchor air-supported structures as shown in Figures 4-5 through 4-8 which illustrate the earth anchorage, concrete anchorage, extruded anchorage, and clamp channel anchorage systems, respectively. In the earth anchorage system (Thermo-Flex, Inc.), small, arrow-shaped anchors are driven into the ground using a jackhammer and the anchors are attached to the cables that support the structure. This type of anchoring system is used if the soil is very compact and it requires no concrete foundations.

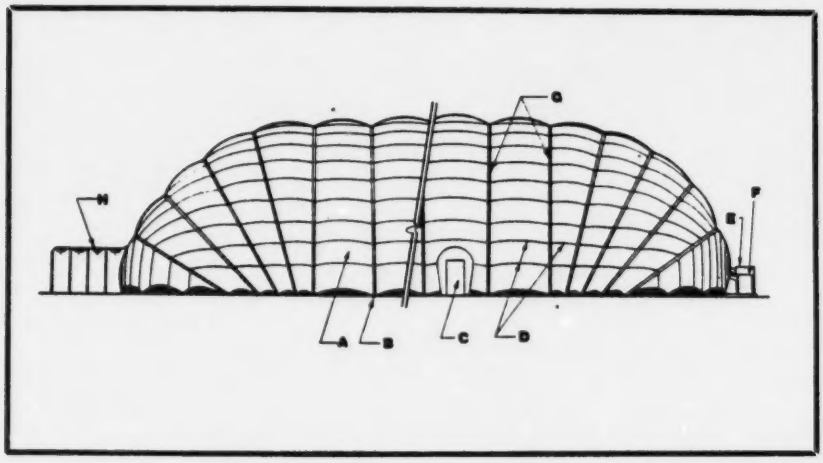
Where soil conditions require a concrete foundation, an extruded anchorage system is used. The base perimeter of the structure is manufactured with a roped bead edge designed to fit into a vinyl channel supplied by the manufacturer; however, wood inserts, designed to hold the roped bead edge in the channel, and the concrete footing, are supplied separately.

The Cloud 9 air structure manufactured by Thermo-Flex is produced in many forms including square, rectangular, L-shaped, circular, elliptical, or oval. The structure can span from 50 feet to 550 feet in width; the length is limitless. Air Structures International (Tappan, NY) produces a structure 300 feet wide by 800 feet long by 100 feet high.

Blowers (fans) are required to keep air-supported structures inflated. These require electricity or generators to provide electricity. Every manufacturer provides backup generators in case of power failure. The Air Structures International system utilizes three 20 horsepower fans.

Materials of Construction

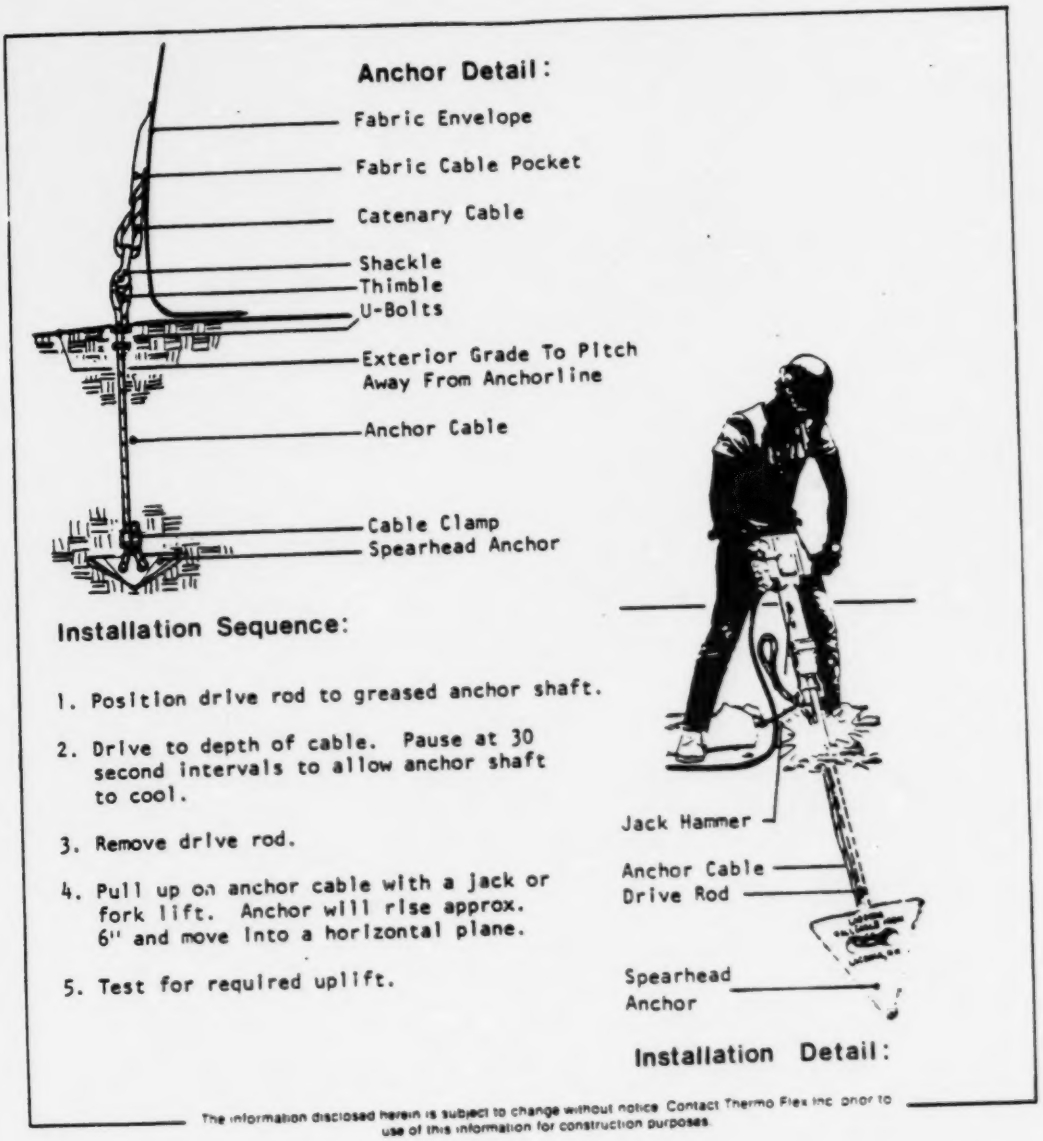
There are a variety of fabrics available commercially to be used for the air-supported structure. Some of the common fabrics used are vinyl-coated polyester, polyvinyl chloride (PVC), and XR-5®, which can be covered with coatings such as Tedlar® to improve the chemical inertness of the fabric. The manufacturers of the air-supported structures report that the fabrics could be coated to be compatible with specific lagoon characteristics.



A. Vinyl Coated Polyester Material
B. Anchorage System
C. Personnel Access
D. Heat Sealed Construction Method
E. Inflation and Heating Systems
F. Auxiliary Stand-By System
G. Stress Relief System
H. Vehicle Access

Reprinted courtesy of Thermo-Flex Inc., Salina, KS.

Figure 4-4. Air-Support Structure (Thermo-Flex)


Anchor Detail:
Fabric Envelope
Fabric Cable Pocket
Catenary Cable
Shackle
Thimble
U-Bolts
Exterior Grade To Pitch Away From Anchorline
Anchor Cable
Cable Clamp
Spearhead Anchor
Installation Sequence:
1. Position drive rod to greased anchor shaft.
2. Drive to depth of cable. Pause at 30 second intervals to allow anchor shaft to cool.
3. Remove drive rod.
4. Pull up on anchor cable with a jack or fork lift. Anchor will rise approx. 6" and move into a horizontal plane.
5. Test for required uplift.
Jack Hammer
Anchor Cable
Drive Rod
Spearhead Anchor
Installation Detail:
The information disclosed herein is subject to change without notice. Contact Thermo Flex Inc. prior to use of this information for construction purposes.

Reprinted courtesy of Thermo-Flex Inc., Salina, KS.

Figure 4-5. Earth Anchorage System

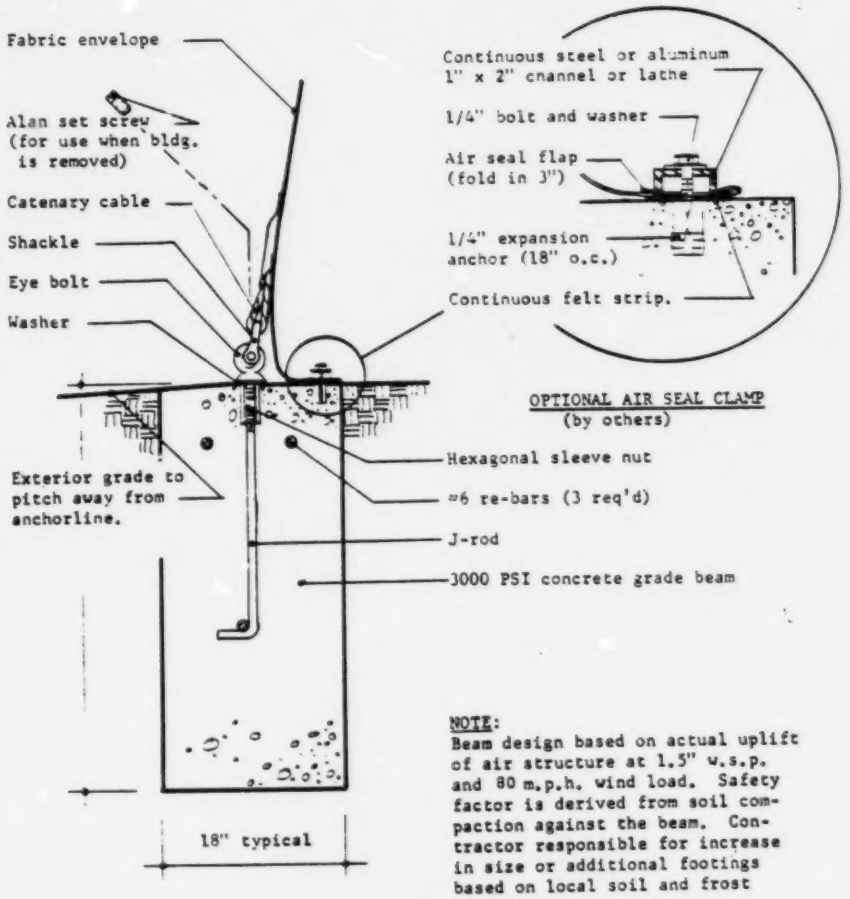

Fabric envelope
Alan set screw (for use when bldg. is removed)
Catenary cable
Shackle
Eye bolt
Washer
Exterior grade to pitch away from anchorline.
Continuous steel or aluminum 1" x 2" channel or lathe
1/4" bolt and washer
Air seal flap (fold in 3")
1/4" expansion anchor (18" o.c.)
Continuous felt strip.
OPTIONAL AIR SEAL CLAMP (by others)
Hexagonal sleeve nut
#6 re-bars (3 req'd)
J-rod
3000 PSI concrete grade beam
18" typical
NOTE:
Beam design based on actual uplift of air structure at 1.5" w.s.p. and 80 m.p.h. wind load. Safety factor is derived from soil compaction against the beam. Contractor responsible for increase in size or additional footings based on local soil and frost conditions.

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Figure 4-6. Concrete Anchorage System

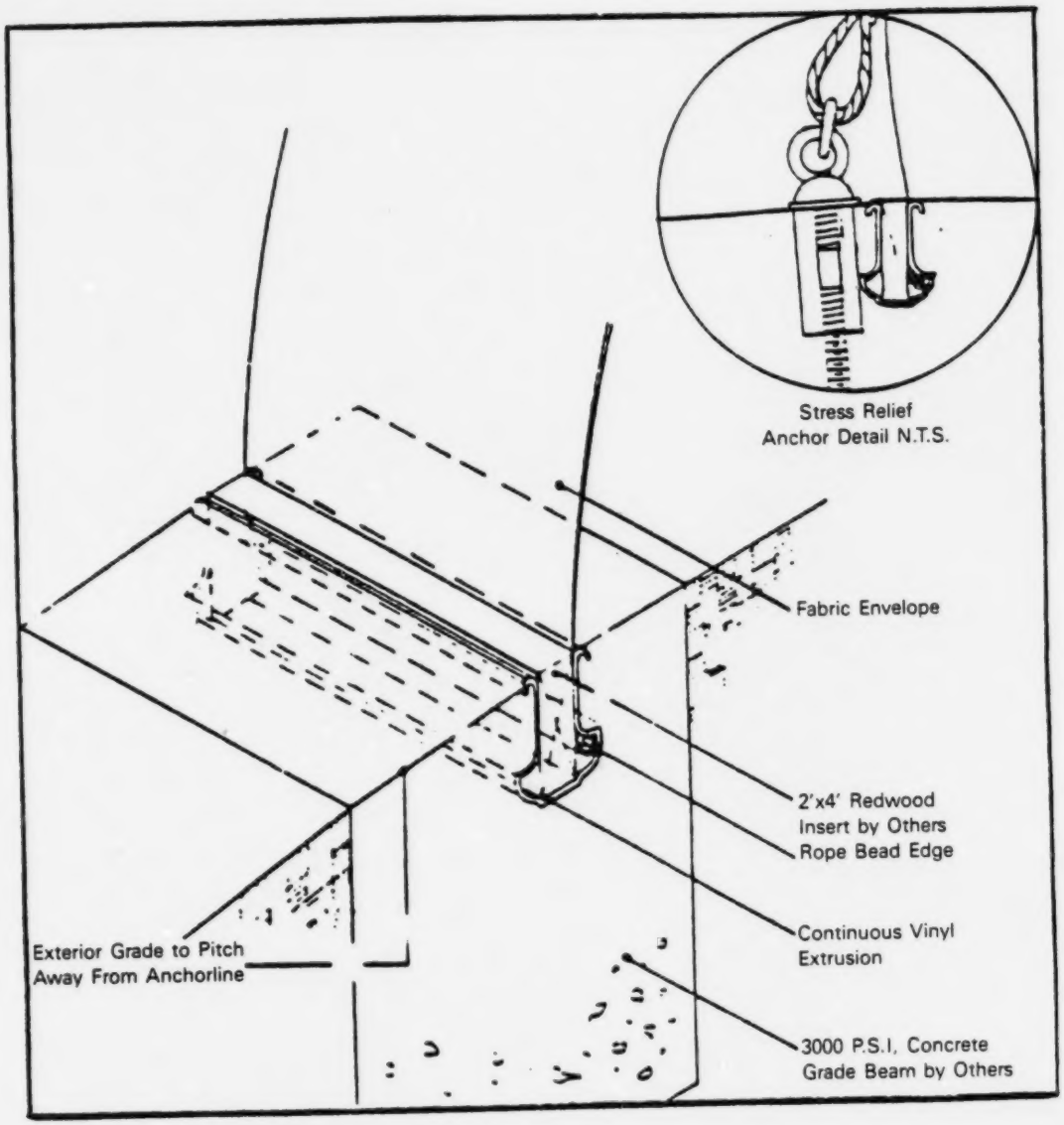

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Figure 4-7. Extruded Anchorage System

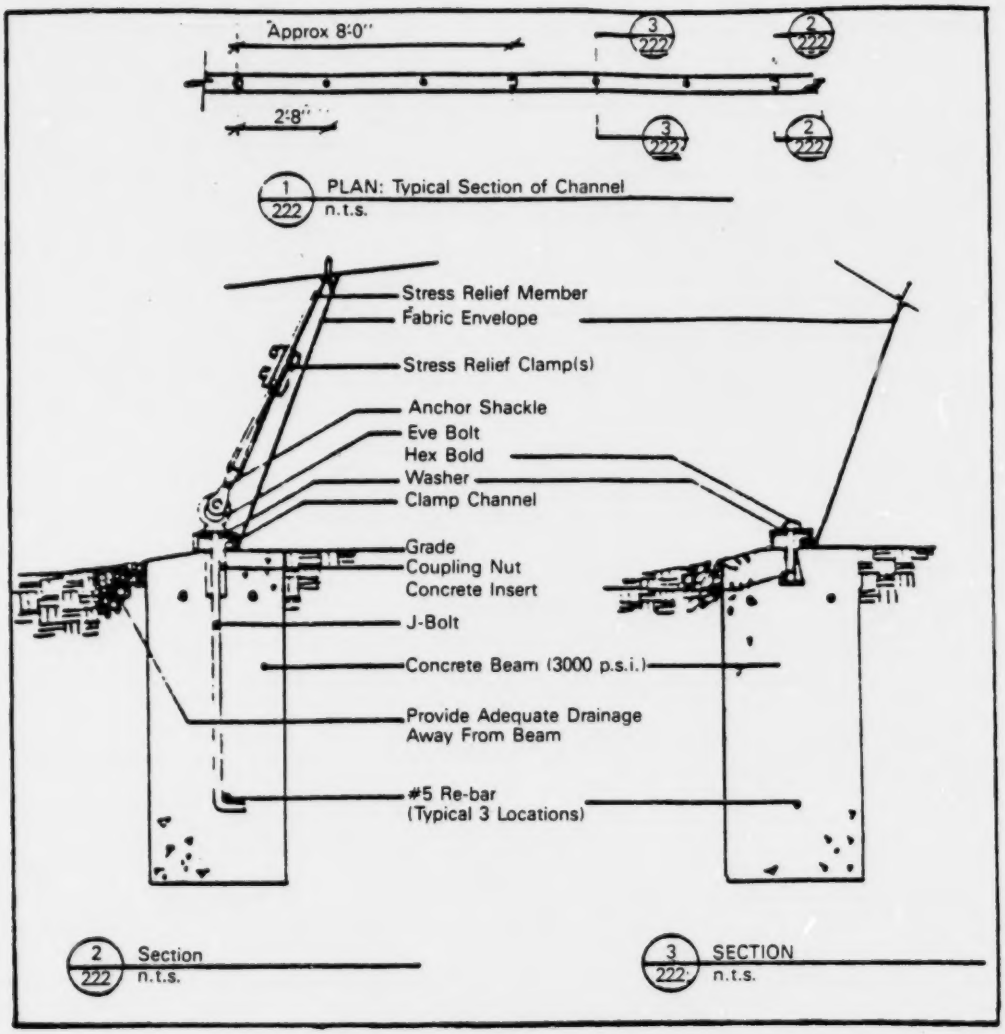

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Figure 4-8. Channel Anchorage System

Installation

Air-supported structures are usually sectionalized for ease of transport, handling, erection, and dismantling. Air Tech Industries (East Rutherford, NJ) usually transports the material in 6 x 6 x 6-foot sections on large wooden pallets. Once on-site, the fabric can be spread out, joined together with aluminum clamps to make the building air- and watertight, anchored to the foundation, then inflated (B. Julien, Air-Tech Industries, personal communication, 1984). Delivery of materials requires 5 weeks to 5 months.

Auxiliary Systems

Enclosed structures such as the air-supported structures require controls for vapor and condensate buildup. In order to avoid vapor buildup, a venting system is also available; this requires additional blowers in order to keep the structure inflated. Condensate control measures such as a trough encircling the interior of the structure may be necessary to return the liquid to the lagoon and prevent leakage to the environment.

These structures require automatic control systems including a pressurization control panel to provide continual operation of the primary blower(s). These systems also automatically control the secondary blower(s) in the event of a pressure drop or power failure. The automatic control system is included in the support structure price.

Heating systems for snow removal and an air pollution control system (if necessary) are available at additional cost (R. Morrison, Thermo-Flex Inc., personal communication, 1984).

Special Factors

There is very little maintenance and monitoring needed for air-supported structures. The only monitoring necessary is to check for possible pressure drops and a check every two weeks of the backup power system (J. Weener, Air Structure International, personal communication, 1984). The life expectency of these structures is approximately 15 to 20 years. The system can be decontaminated, deflated, and reused at a different site.

Costs

The costs of air-supported structures vary according to the manufacturer, the size of the building, the choice of coated fabric, the earthwork and foundation necessary, and miscellaneous equipment such as heating and ventilation systems required for proper functioning of the structure. Air Structures International quoted a price range for materials of \$4 to \$8/ft^2; Air Tech Industries quoted a price of \$2.75 to \$5.75/ft^2; and Thermo-Flex quoted a price range of \$3.50 to \$7.50/ft^2. The manufacturers also indicated that the installation costs range from \$0.50 to \$2/ft^2 depending on the site work and foundation necessary. Therefore, the total costs range from \$3.25/ft^2 to \$10/ft^2.

Electrical costs vary according to the size of the structure and the number of blowers used to keep the structure inflated. For example, a struc-

ture 300 feet x 800 feet (5.5 acres) utilizing three 7.5 horsepower fans may have an electrical cost between $1,500 and $2,000/year, while the same size structure using three 20 horsepower fans (ventilation purposes) may have electrical costs ranging from $4,000 to $5,000/year (depending on location). Additional operating costs include the cost of heating and air pollution control systems. These costs also need to be determined before final selection is made.

Summary

Air-supported structures can cover lagoons of many configurations and sizes. Their total costs range from $3 to $10/ft and are thus highly competitive with other technologies used for overtopping control.

The coated fabric used in the structure can be selected to be compatible with the contents of the lagoon. Heating, ventilation, condensate, and air pollution controls can also be designed to meet specific lagoon and site requirements. These systems impose additional costs to the cover system; however, the cover can be decontaminated and is reusable.

There are several limiting factors for the application of this system. If the smallest lagoon dimension is greater than 550 feet, this system cannot be used. The soil conditions may preclude certain anchoring systems or require the construction of concrete anchoring bases, which will increase the system cost.

FLOATING COVER SYSTEMS

A floating cover consists of a lining placed in one piece over an impoundment with proper anchoring at the edges and floats to prevent the lining from submerging. This system of covering impoundments is being adopted widely throughout the country for water reservoirs. According to industry officials, approximately 80 to 85 percent of all floating covers have been constructed over potable waters reservoirs. The remaining 15 to 20 percent have been used at biodegradation facilities, slaughterhouses, chemical treatment ponds, toxic waste lagoons, and fish hatchery ponds (Evans and Meade, 1984).

System Design

Burke Industries, Inc., and Globe Lining, Inc., have patents for their design of flexible covers; Globe has an additional patent for an associated gas collection system. These two designs, with slight modifications, are reflected in virtually every floating cover that has been installed to date (Evans and Meade, 1984).

The Globe design is primarily based on a rainwater collection sump around the perimeter of the cover. Rainwater is directed toward this sump by various configurations of foam floats that are inserted and sealed into special pockets in the cover (Evans and Meade, 1984).

The most common float configuration consist of one large center float with smaller lateral floats attached perpendicularly at about 36-foot centers.

Figure 4-9 provides an illustration of this system. After the sump at the perimeter of the cover fills with water, it is drained either by random pumping with a portable pump, or by installing a flexible perforated hose in the area of the fold that is formed by the collected water (Evans and Meade, 1984).

The Burke Design presents a completely different method of draining rainwater from the floating cover. This design consists of channels in the middle of the cover created by strings of segmented sand-filled tubes held at a constant depth by floats on either side of the channel. This design is illustrated in Figure 4-10. The sand-filled tubes are connected in parallel to flexible perforated collection tubes above and to the cover underneath. Rainwater, after striking the cover, drains through openings in the floats lining the collection channels, and is pumped off the cover through the collection tubes (Evans and Meade, 1984).

Neither cover system can be applied to situations where substantial debris exists in the lagoon that cannot be removed. Such debris can cause tears in the cover through wind or precipitation action.

Materials of Construction

About 90 percent of all floating covers are made with reinforced Hypalon either 35 or 45 mils thick. Hypalon (a chlorosulfonated polyethylene) is resistant to most chemicals and weather conditions, is the easiest material to seam in the field, and is among the least expensive cover materials. Two earlier cover materials, ethylene-propylene-diene-monomer (EPDM) and butyl rubber, were abandoned after Hypalon was discovered because of their tendency toward cracking and seaming problems. The second most popular material for floating covers is reinforced chlorinated polyethylene, 35 or 45 mils thick. This material costs about the same as Hypalon but has not been as effective, therefore, its use in covers is declining (Evans and Meade, 1984).

The main limitation of Hypalon as a cover material for liquids other than potable water is its low resistance to oil derivatives such as kerosene, diesel fuel, and hydraulic fluids. Another alternative to Hypalon is XR-5® made by the Shelter-Rite Company. Like the other alternatives to Hypalon, XR-5® is more difficult to field seam and is approximately twice as expensive (Evans and Meade, 1984).

Chemical resistance to specific lagoon contents should be checked prior to final selection.

Installation

Sections of cover materials are shipped to a site on large wooden pallets and can be delivered within 7 to 10 days of ordering. All pockets for insertion of flotation devices are generally made at the fabrication plant prior to shipment.

The cover segments are seamed together in the field. Cables are attached along the leading edges of the joined cover segments so the cover

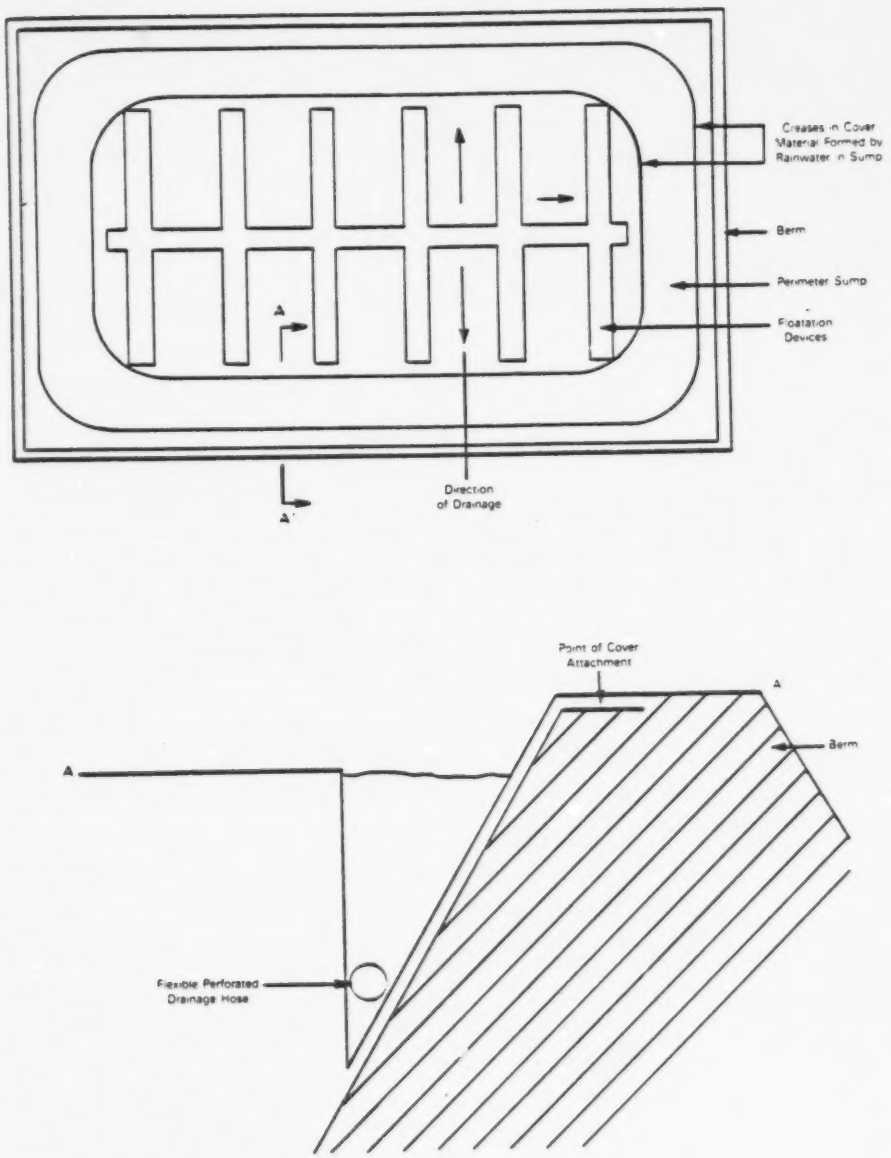

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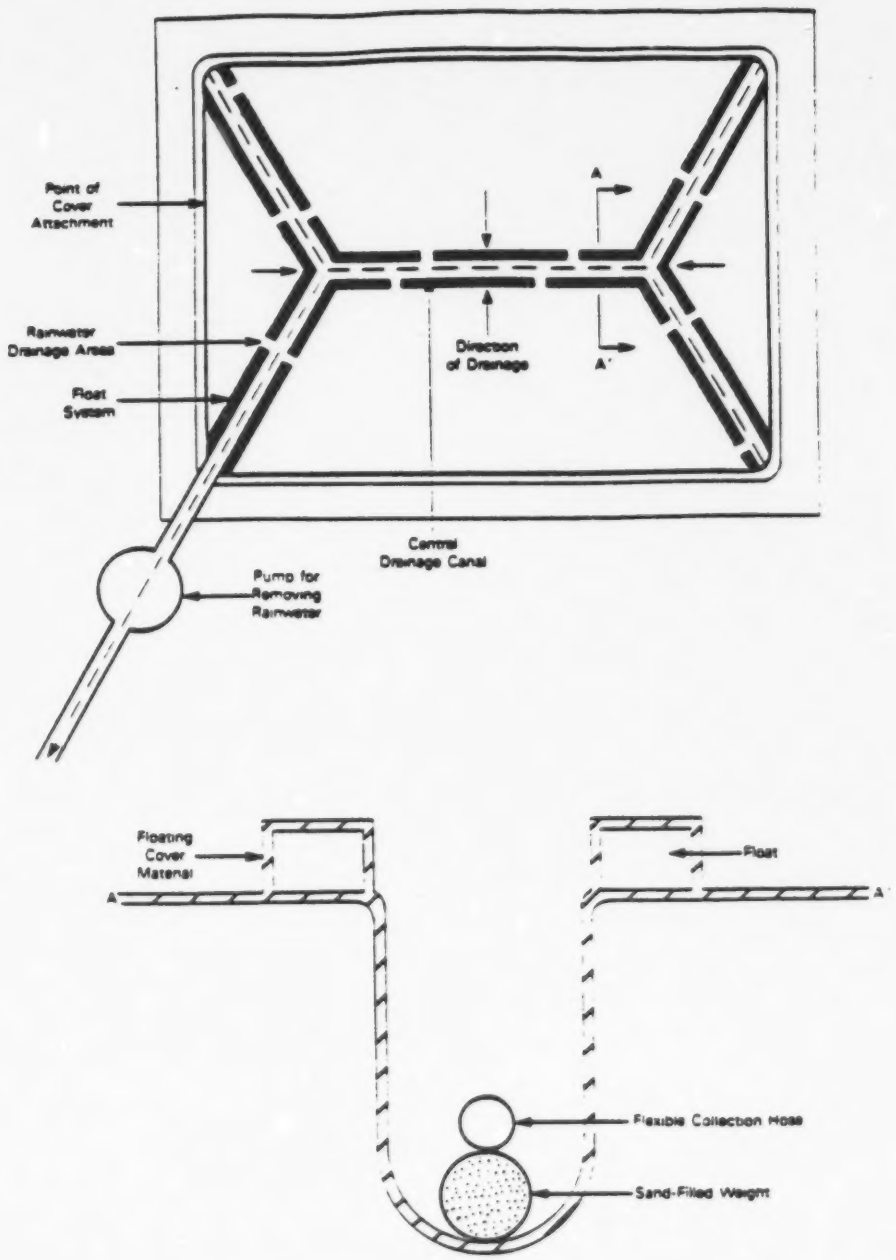
Figure 4-9. Schematic Plan and Cross-Section of a Floating Cover Incorporating the Patented Globe Design



Reprinted with permission of Burke Industries, Inc., San Jose, CA.

Figure 4-10. Schematic Plan and Cross-Section of a Floating Cover Incorporating the Patented Burke Design

section can be dragged across the lagoon. Floats are inserted into their pre-formed pockets, which are then seamed shut (Evans and Meade, 1984).

Before the cover can be installed, debris must be removed from the surface to prevent damage to the cover. This may involve skimming floating material from the surface or removing larger items such as drums.

There are two anchoring systems for floating covers. One anchoring method requires the installation of a concrete curb with bolts at 12-inch intervals fitted into pre-cut, reinforced holes in the cover fabric, then through holes in metal battens. These battens are bolted down to produce a continuous seal around the perimeter of the cover. A second, less expensive method involves digging a 12-inch wide by 18-inch deep trench around the lagoon. About 40 inches of the floating cover are placed into the trench to conform with trench sides and bottom, then the trench is backfilled with soil, which is compacted with heavy equipment (Evans and Meade, 1984).

On large lagoons, the anchor systems should be augmented with a mechanism to counteract the effects of strong winds. One such method is achieved by stringing cables from the cover to the bottom of the lagoon at regular intervals. In this design, the stress from wind is shared by the perimeter anchors and the bottom anchors (Evans and Meade, 1984).

Auxiliary Systems

Gas collection systems may be necessary if lagoon contents are highly volatile. The patented Globe gas collection system is designed for connection to the solid foam floats on the Globe cover. Because of the similiarity of float system designs, the Globe gas collection system could be fitted to virtually any floating cover. The gas collection system consists of several air chambers formed at various points along the cover flotation system. Figure 4-11 illustrates this system. Each chamber is covered by the floating cover material and is equipped with an opening allowing gases to flow up through an air chamber from the triangular-shaped space formed between the cover, the covered liquid, and the float. The upper end of the air chamber is connected to a short standpipe, a few inches in diameter, then to a manifold pipe to allow pumping of gases (Evans and Meade, 1984).

Special Factors

Currently, floating covers are designed for a life of up to 30 years. The cover system should be examined on a regular basis to identify any punctures or any swelling resulting from the corrosive properties of the lagoon contents.

It may be possible to reuse a floating cover at another site. However, the cover must be decontaminated and tested for strength and durability before reuse (Evans and Meade, 1984).

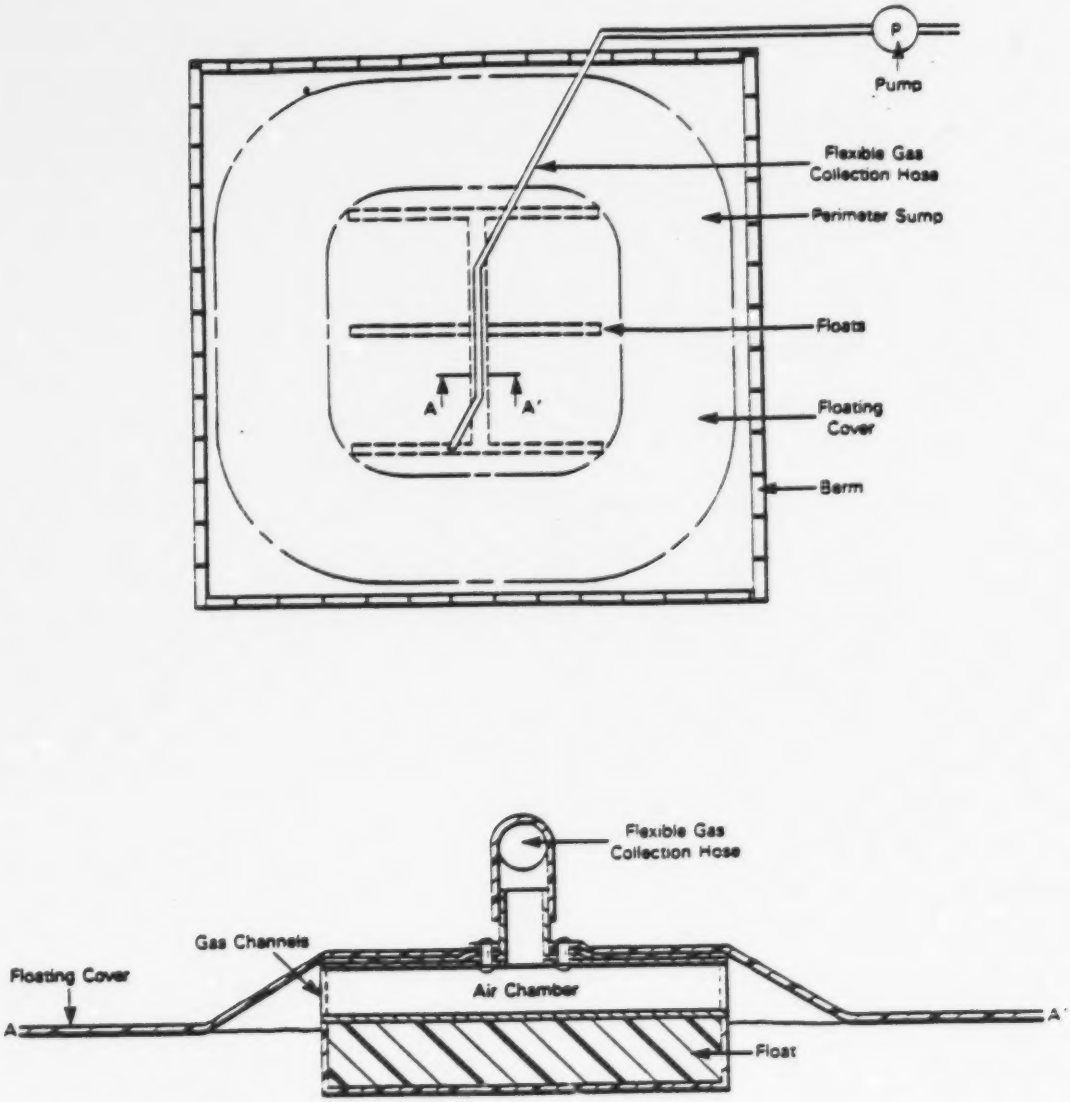


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Figure 4-11. Schematic Plan and Cross-Section of a Patented Globe Floating Cover and Gas Collection System Design

Costs

Floating covers range in cost from \$2.50 to \$3.50/ft^2. However, to address site preparation, berm stability, and gas emission problems, the cost of the floating cover would be \$2 to \$3/ft^2 higher, leading to a total cost ranging from \$2.50 to \$6.50/ft^2 (Evans and Meade, 1984). Additional costs may be incurred to remove debris from the lagoon; these costs will vary depending on the materials to be removed and the removal methods employed.

Summary

Floating covers are less expensive than any other type of covering system and range in total cost between \$2.50 and \$6.50/ft^2. The lining material used can vary according to the contents of the lagoon; Hypalon is the most common type of liner used. An XR-5® liner is more chemically inert but is difficult to field seam and is approximately twice as expensive as Hypalon. Use of a floating cover is limited if there is a substantial amount of debris on the surface of the lagoon or submerged in the lagoon that may puncture the cover. Another limitation of the floating cover is that the fabric may not be reusable due to swelling from exposure to lagoon contents.

SECTION 5

SURFACE WATER DIVERSION AND BERM IMPROVEMENTS

Lagoons may overflow due to surface water run-on or berm degradation. This section discusses options that either maintain or increase the holding capacity of the lagoon by:

- Diversion of liquid inflow from surface run-on through the use of ditches, diversions, dikes, and berms.
- Prevention of waste material outflow through the construction or reconstruction of berms.

These control options are unique relative to overtopping controls discussed in earlier sections as they are directed at preventing overtopping through measures applied external to the impoundment (i.e., on the walls or surrounding areas.)

SURFACE WATER CONTROLS

Surface water controls are improvements external to the impoundment and its immediate area that prevent liquids from entering the impoundment or eroding impoundment walls. When designed, constructed, and maintained correctly, surface water controls can extend the useful life of the impoundment by either preventing run-on, which fills available lagoon capacity, or reducing wall degradation, which lessens available lagoon capacity. Surface water control techniques include:

- Ditches, diversions, and waterways: small drainageways that intercept and divert run-on away from an impoundment.
- Diversion and interceptor berms and dikes: structures that intercept and divert run-on away from an impoundment.
- Terraces and benches: wide drainageways that slow down run-on and divert it to ditches and diversions.
- Levees and floodwalls: embankments used to prevent contact of floodwaters and tides with the impoundment.

These options are discussed in more detail below.

Ditches, Diversions, and Waterways

Ditches and diversions are excavated, temporary drainageways used along the contours of slopes to intercept and divert run-on away from the impoundment to natural or man-made drainageways (e.g., streams, rivers, waterways, sedimentation ponds). Ditches are distinct from diversions in that they are simple excavations in the slope that channel water. Diversions incorporate the ditch but also include a supporting ridge on the down-slope side. Ditches and diversions are useful where run-on from precipitation is the only problem uncomplicated by streams or floods that could overwhelm the capabilities of the im-

poundment structure. Grassed waterways are used where the impoundment is downslope of run-on that would otherwise enter the impoundment, or where run-on could erode the impoundment wall. Waterways are graded drainageways used at the ends of ditches and diversions to remove collected drainage at non-erosive velocities (JRB Associates, 1982b).

Design Options--

Ditches and diversions are generally of a V-shaped, trapezoidal, or parabolic cross-section design. The specific design will depend on local drainage patterns, soil permeability, annual precipitation, area land use, and other pertinent characteristics of the contributing watershed. These structures should be designed and constructed to intercept and convey flows at non-erosive velocities. A general guideline is: the wider and shallower the channel/waterway cross-section, the lower the velocity of the contained flow and, therefore, the lower the potential for erosion of drainageway side slopes. Where local conditions necessitate building a narrower and deeper channel/waterway, or where slopes are steep and flow velocities are excessive, the channel/waterway will require stabilization through the use of liners, seeding and mulching, or stone rip-rap to line channel bottoms and break up the flow (JRB Associates, 1982b).

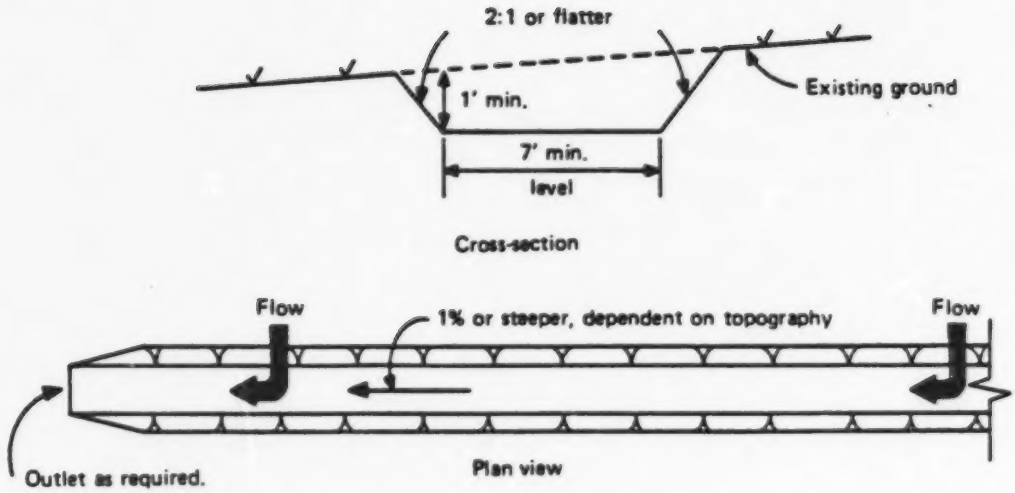
Figure 5-1 illustrates the standard design for drainage ditches. These structures are designed only for short-term application to up-slope drainage areas of less than 5 acres. Temporary ditches should have a minimum grade of one percent draining to a stabilized outlet such as a grassed waterway or, where necessary, to a sediment basin or trap. For channel slopes greater than 5 percent, stabilization with grasses, mulches, sod, or stone rip-rap will be necessary. As with all temporary structures, periodic inspection and maintenance are required to ensure structural integrity and effective performance (JRB Associates, 1982b).

Figure 5-2 presents general design features of parabolic and trapezoidal diversions. A formal design is not required for diversions used as temporary water-handling structures. All trees, bushes, stumps, and obstructions should be cleared to prevent improper functioning of the channel; however, care should be taken to avoid the removal of root systems that may structurally weaken channel or impoundment walls. Stone centers may be necessary to reduce flow velocities (JRB Associates, 1982b).

Figure 5-3 depicts general design configurations for grassed waterways; Figure 5-4 illustrates grassed waterways with stone centers. The design and construction criteria presented above for diversions are also applicable to grassed waterways (JRB Associates, 1982b).

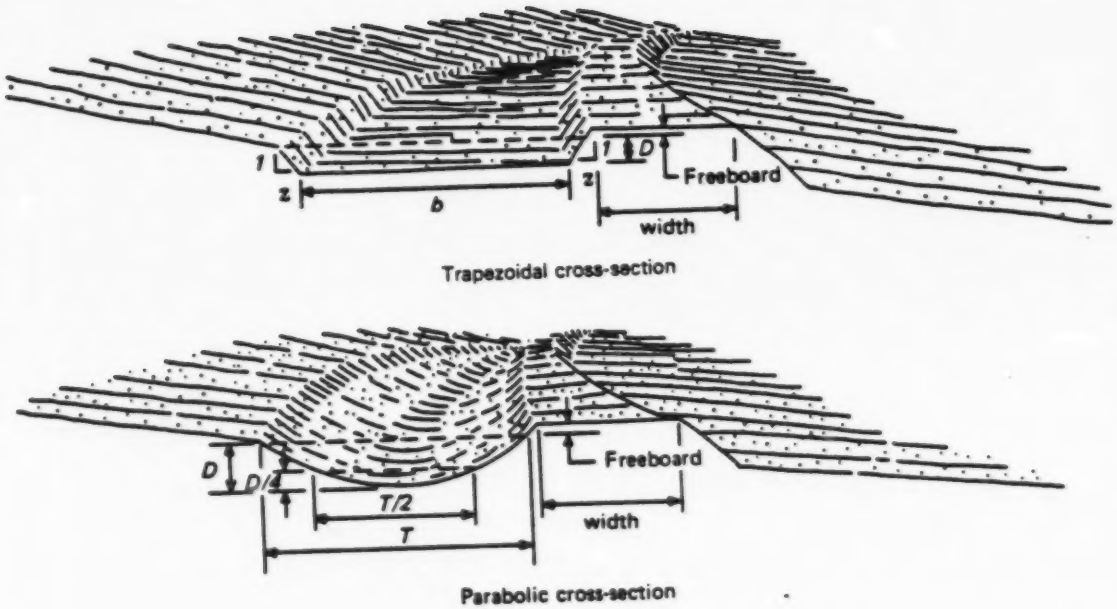
Installation--

Installation of ditches and diversions is dependent upon the materials selected. Drainageways excavated and constructed from on-site materials will be easier and less costly to install than those using off-site materials. Liners such as asphalt or cement may be used but will increase the cost (JRB Associates, 1982b).



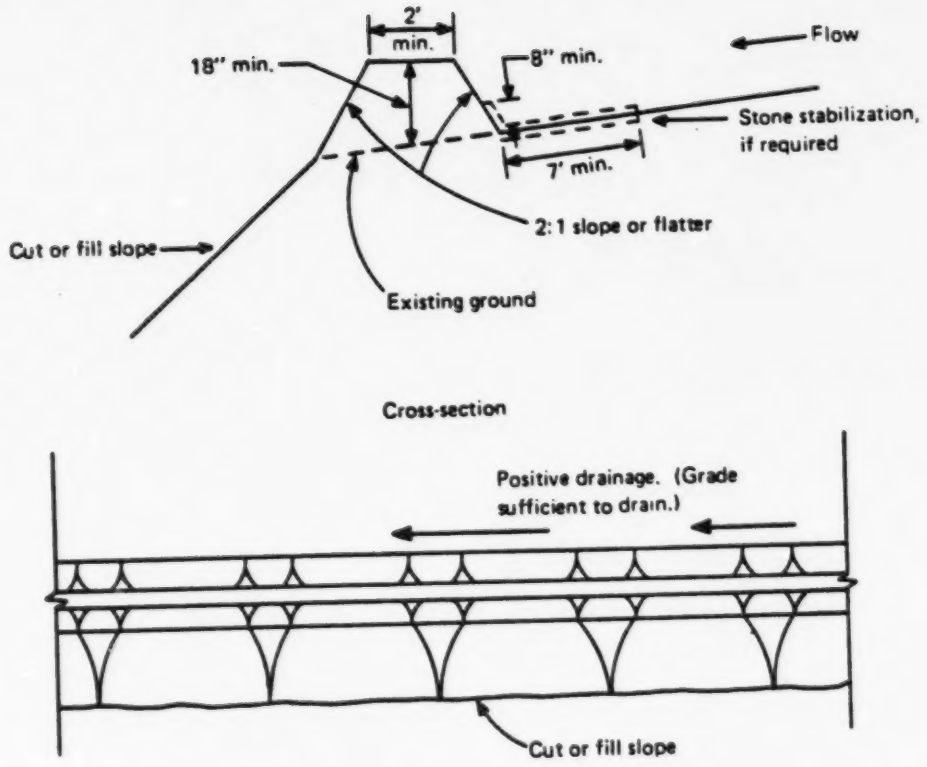
Source: JRB Associates, 1982b

FIGURE 5-1. STANDARD DESIGN FOR DRAINAGE DITCHES



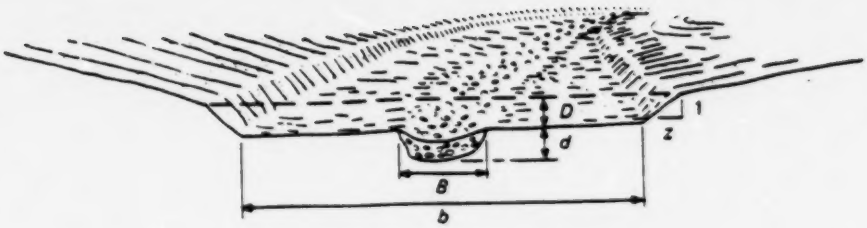
Source: JRB Associates, 1982b

FIGURE 5-2. GENERAL DESIGN FEATURES OF DIVERSIONS

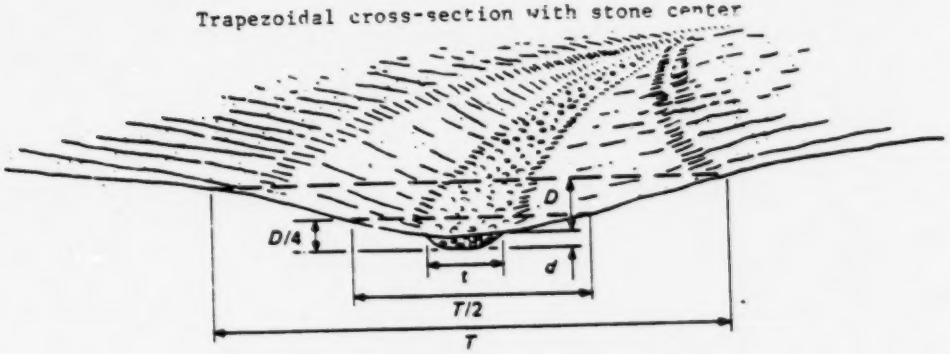


Source: JRB Associates, 1982b

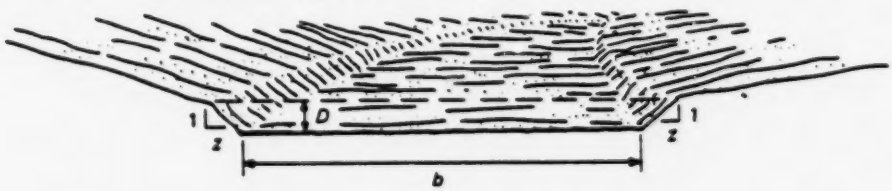
FIGURE 5-3. TEMPORARY DIVERSION DIKE



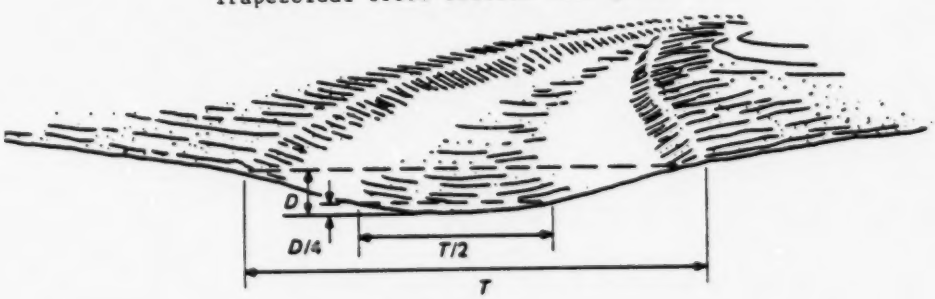
Trapezoidal cross-section with stone center



Parabolic cross-section with stone center



Trapezoidal cross-section with grass



Parabolic cross-section

Source: JRB Associates, 1982b

FIGURE 5-4. GRASSED WATERWAYS WITH STONE CENTER

Site-specific factors may also greatly limit options. It may be more difficult to bring in construction materials to impoundments located in isolated areas where on-site materials are unsuitable. Also, surrounding areas that are extremely wet and/or unsupportive due to the ecology or season will be less conducive to the application of cement or asphalt liners which require the use of heavy machinery. Furthermore, steeper areas require more extensive drainage control networks and therefore more construction, excavation, and associated materials.

The installation of ditches, diversions, and waterways may disturb local vegetation. Brush and shrubs may need to be removed to install drainageways. Removal of the vegetative cover may actually increase drainage and aggravate erosion. Thus, it may be necesary to grade and revegetate the affected area.

The demolition of temporary drainageways to allow for machinery access and final response action activities also depends upon the design selected and materials used. Simpler structures may not require special removal prior to final site response action; however, more permanent structures lined with cement or asphalt may have to be broken up or removed. In such cases, new ditches and diversions may have to be constructed for the final response action.

Costs--

The costs of temporary drainageways are dependent upon the following factors (JRB Associates, 1982b):

- Complexity of option selected
- Extensiveness of area requiring drainage
- Amount and type of non-local materials needed (e.g., cement, asphalt, synthetic liners, or clay)
- Difficulty of access to the area (especially for heavy machinery)
- Extent of existing drainageways contributing to the problem and or areas not covered by vegetative matter (e.g., volume and source of run-on).
- Maintenance and inspection required (e.g., mowing grasses to prevent ponding, repairing walls, or filling cracks)
- Severity of weather patterns (e.g., storms or cold temperatures).

These factors will generally increase the cost of the selected option.

Unit costs for construction of ditches, diversions, and waterways are presented in Table 5-1, which includes costs for other diversion structures as well. In general, grading costs to prepare a site range from $\$1/yd^3$ to $\$13/yd^3$ depending upon materials used and their transportation. Trench excavation

TABLE 5-1. UNIT COSTS ASSOCIATED WITH SURFACE WATER DIVERSION AND COLLECTION STRUCTURES

Description	Applicable Structures	Approximate Total Cost* ($)
o Grading	All	
- Topsoil (sandy loam), hauling, spreading, and grading (within 20 miles); labor, materials, and equipment		13.50/yd^3
- On-site excavation, hauling, spreading, and compaction of earth (1,000 - 5,000' haul); labor and equipment		1-2/yd^3
- Loam topsoil; material only		5/yd^3
- Excavate, haul 2 miles, spread and compact loam, sand, or loose gravel (with front and end loader); labor and equipment only		1-2/yd^3
- Grading site excavation and fill (no compaction) 75 hp dozer, 300' haul 300 hp dozer, 300' haul		 2/yd^3 1.50/yd^3
- Testing soils for compaction		28/sample
o Trench Excavation	All except SB	
- Trench excavation with 2 inch gravel fill		4/linear ft
- Grass lined trench assuming 2 inches of topsoil		6.50/ft
- Concrete lined trench: concrete lined trench, 4 inch concrete wire mesh, reinforced assuming use of 2 forms and expansion joint every 12 feet		22/linear ft

(continued)

* Total cost includes material, overhead, and profit

Key: D/B = Dikes and Berms (interceptor, diversion, or structures used to increase impoundment height)
D/D/W = Ditches, Diversions, and Waterways
BT = Bench Terraces
L = Levels
DT/B = Drainage Trenches and Basins
SB = Sediment Basins

TABLE 5-1. (continued)

Description	Applicable Structures	Approximate Total Cost* ($)
o Building embankments; spreading shaping, compacting:	All	
material delivered by scraper		0.20-0.40/yd^3
material delivered by back dump		0.50-0.65/yd^3
o Placement of ditch liner pipe:	D/D/W; drainage benches	
1/3 section, 15" radius		10/ft
18" radius		15/ft
24" radius		19/ft
o Catch basin sump, 3'x4'x1.5'	L; DT/B	152 each
o Corrugated galvanized steel underdrain pipe, asphalt-coated, perforated	DT/B	
12" diameter, 16 gage		12.50/ft
18" diameter, 16 gage		17.50/ft
o Steel sheet piling;	L (seepage control)	
15' deep, 22 psf		8.50/ft^2
20' deep, 27 psf		10/ft^2
25' deep, 38 psf		12.50/ft^2
o Backflow preventer: gate valves, automatic operation, flanged, 10" diameter	L (drainage control)	9,140 each
o Floating baffles	SB	21-51/ft
o Sump pumps: 6"-12" centrifugal pumps, operating 1 shift/day	L (backwater drainage)	170-246/day

(continued)

* Total cost includes material, overhead, and profit

Key: D/B = Dikes and Berms (interceptor, diversion, or structures used to increase impoundment height)
D/D/W = Ditches, Diversions, and Waterways
BT = Bench Terraces
L = Levels
DT/B = Drainage Trenches and Basins
SB = Sediment Basins

TABLE 5-1. (continued)

Description	Applicable Structures	Approximate Total Cost* ($)
o Loose gravel, excavation, loading, hauling 5 miles, spread and compacting	All (slope protection; drainage)	4-4.50/yd^3
o Stone rip-rap: dumped from trucks, machine-placed	All (slope protection; channel and outlet stabilization)	17/yd^3
o Soil testing	All (preconstruction evaluation)	
liquid and plastic limits		36/test
hydrometer analysis; specific gravity		61.50/test
moisture content		8/test
permeability		51.50/test
proctor compaction		41-46/test
shear tests, triaxial		200-360/test
direct shear		77-231/test
o Temporary sediment construction; drainage area:	SB	
1-25 acres		310-1,640 each
50-75 acres		3,080-5,130 each
75-100 acres		5,130-6,580 each
100-125 acres		6,580-8,220 each
o Sediment removal from basins	SB	3-7/yd^3
o Paved flume, installed	SB	20.50-31/yd^2
o Level spreader construction	D/B; D/D/W; BT	2.50-5/linear ft

(continued)

* Total cost includes material, overhead, and profit

Key: D/B = Dikes and Berms (interceptor, diversion, or structures used to increase impoundment height)
D/D/W = Ditches, Diversions, and Waterways
BT = Bench Terraces
L = Levels
DT/B = Drainage Trenches and Basins
SB = Sediment Basins

TABLE 5-1. (continued)

Description	Applicable Structures	Approximate Total Cost* ($)
o Revegetation	All	
- Total - revegetation with grass including stockpile and spreading topsoil (500 feet), fine grading, seeding and mulching		3,130/acre
- Shrubs (balled and burlapped)		
2 to 3 feet (height)		18 each
2 to 4 feet (height)		28.50 each

* Total cost includes material, overhead, and profit

Key: D/B = Dikes and Berms (Interceptor, diversion, or structures used to increase impoundment height)
D/D/W = Ditches Diversions, and Waterways
BT = Bench Terraces
L = Levels
DT/B = Drainage Trenches & Basins
SB = Sediment Basins

Source: JRB Associates, 1982a; JRB Associates, 1982b

costs for all options range from $3/linear foot to $21/linear foot depending on materials used and intended design life.

Interceptor and Diversion Dikes and Berms

Within the context of this analysis, berms and dikes are well-compacted earthen ridges constructed outside the perimeter walls of an impoundment to prevent surface run-on. The two terms, dikes and berms, are used interchangeably.

Interceptor and diversion dikes and berms are placed immediately up-slope from or along the perimeter of an impoundment to prevent surface waters from entering and filling the impoundment. Run-on waters can be intercepted and diverted to natural or man-made drainageways or stabilized outlets. In this application, dikes and berms may prevent excessive erosion of newly constructed slopes until more permanent drainage structures are installed or until the slope is stabilized with vegetation. These temporary structures are designed to handle relatively small amounts of run-on and are not suitable for unsloped drainage areas larger than 5 acres (JRB Associates, 1982b).

Interceptor diversion dikes and berms are distinct from levees and floodwalls in the context of this discussion. Diversion dikes and berms are used to intercept run-on; levees and floodwalls are used to control flood and tidal waters. Interceptor dikes and berms are inadequate for the purposes of controlling flood and tidal waters.

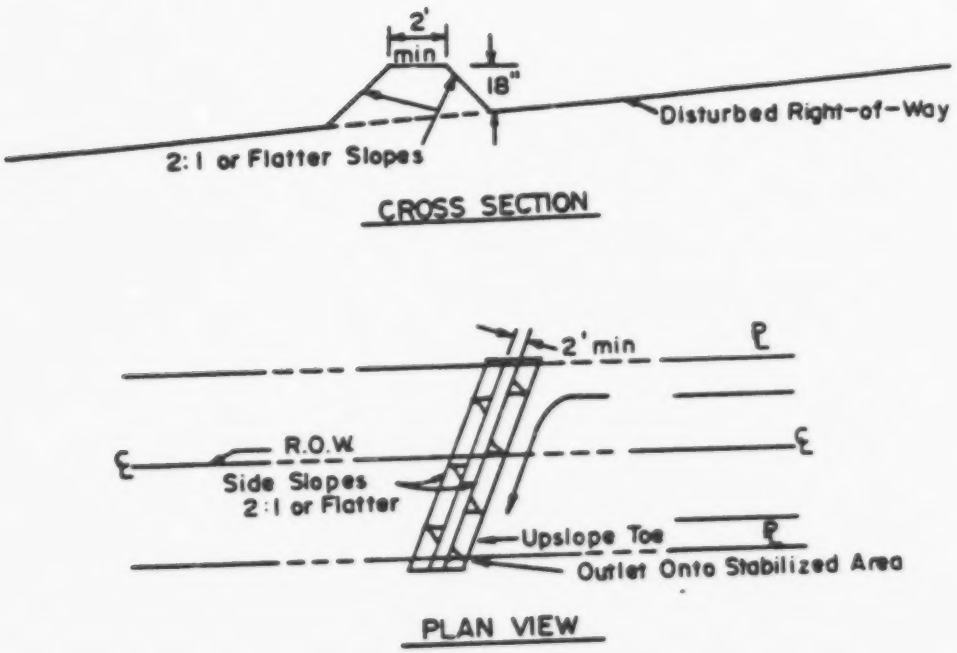
Design--

Specific design and construction criteria for berms and dikes will depend upon the site-specific functions of the structures. An interceptor dike or berm, shown in Figure 5-5, may be used to shorten the length of exposed slopes above an impoundment, thereby reducing erosion potential by intercepting and diverting run-on. Diversion dikes or berms may be installed at the top of drainage slopes above impoundments to provide erosion protection by diverting run-on to stabilized channels or outlets (JRB Associates, 1982b).

Diversion and interceptor dikes or berms should be constructed of erosion-resistant, low-permeability, clayey soils. Ideally, materials should be obtained on-site. Compacted sands and gravel, however, may be suitable for interceptor dikes and berms. The general design life of these structures is approximately one year (maximum); seeding and mulching or chemical stabilization of dikes and berms may extend their life expectancy. Stone stabilization with gravel or stone rip-rap immediately up-slope of dikes will also extend performance life (JRB Associates, 1982b).

Common design and construction criteria for interceptor and diversion dikes or berms include the following (JRB Associates, 1982b):

- Drainage area should be no more than 5 acres.
- Grade is dependent upon topography, but should have positive drainage to the outlet; for interceptor dikes/berms - 1.0 to 1.5 percent.



Source: JRB Associates, 1982b

FIGURE 5-5. TEMPORARY INTERCEPTOR DIKE

- All earthen dikes should be machine-compacted where possible.
- Diverted run-off should outlet directly onto stabilized areas, level spreader, grassed channel, or chute/downpipe.
- Diversion dikes should be seeded and mulched immediately after construction.

Structures used to divert flowing surface waters away from the impoundment will require more frequent inspection and repairs to ensure structural integrity and prevent up-slope deposition of sediments.

Installation--

Installation of dikes and berms involves the use of on-site or hauled in materials and construction of the structures. An advantage of dikes and berms is that in many cases wall materials can be found on-site (JRB Associates, 1982b). A right-of-way must be available to bring in heavy machinery. Additionally, the site must be able to support the machinery once on-site.

Diversion and interceptor dikes and berms will likely pose few problems to the final site response action. If not incorporated into the selected response, they may be leveled to gain access to either the impoundment or materials contained within the impoundment.

Costs--

The costs of interceptor and diversion dikes or berms are largely dependent upon the following factors (JRB Associates, 1982b):

- Number and size of structures required
- Amount and type of non-local materials needed (e.g., cement, asphalt, and synthetic liners, etc.)
- Maintenance and repairs required
- Design life of structures
- Amount and type of stabilization required
- Site access problems.

Unit costs for dikes and berms are provided in Table 5-1.

Terraces and Benches

Terraces and benches are relatively flat areas constructed along the contours of very long or very steep slopes to slow down run-on and divert it into ditches or diversions at non-erosive velocities; these structures are also known as bench terraces or drainage benches. Terraces and benches have proven effective in areas of high precipitation not subject to inundation by floods,

streams, or rivers. They are useful in preventing run-on from entering a surface impoundment or eroding its walls (JRB Associates, 1982b).

Although benches and terraces are slope reduction devices, they are generally constructed with reverse fall or natural fall, as shown in Figure 5-6, to divert water to stabilized drainageways. Benches and terraces may be used to break up steeply graded slopes into less erodible segments. Up-slope of impoundment sites, they act to slow and divert storm run-on around the site. Down-slope of impoundment areas, they act to intercept and divert sediment-laden run-on to traps or basins (JRB Associates, 1982b).

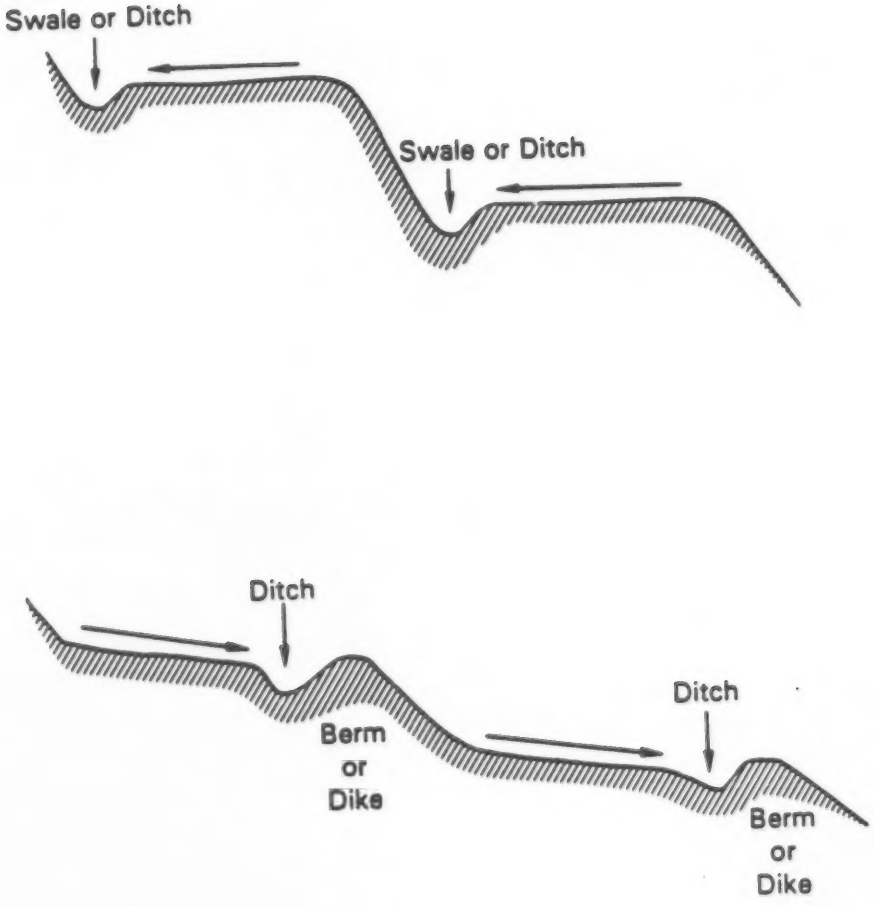
Design Options--

Benches and terraces generally do not require a formal design plan. Figure 5-7 presents the design for a typical drainage bench on a slope. This particular bench is designed with natural fall. It is intended for long-term erosion protection since the associated V-shaped channel is asphalt or concrete lined. Diversions and ditches included in bench/terrace construction may be seeded and mulched, sodded, stabilized with rip-rap or soil additives, or stabilized by any combination of these methods. Lining the channels with concrete or grouted rip-rap is a more costly alternative (JRB Associates, 1982b).

The width and spacing between benches and terraces will depend on the slope steepness, soil type, and slope length. In general, the longer and steeper the slope and the more erodible the cover soil, the less the distance there should be between drainage benches. Such design maximizes the erosion reduction afforded by constructed benches. For slopes greater than 10 percent in steepness, the maximum distance between drainage benches should be approximately 100 feet, (i.e., a bench every 10 feet of rise in elevation). For slopes greater than 20 percent, benches should be placed every 20 feet of rise in elevation (JRB Associates, 1982b). Thus, the steeper the slope, the more construction is required.

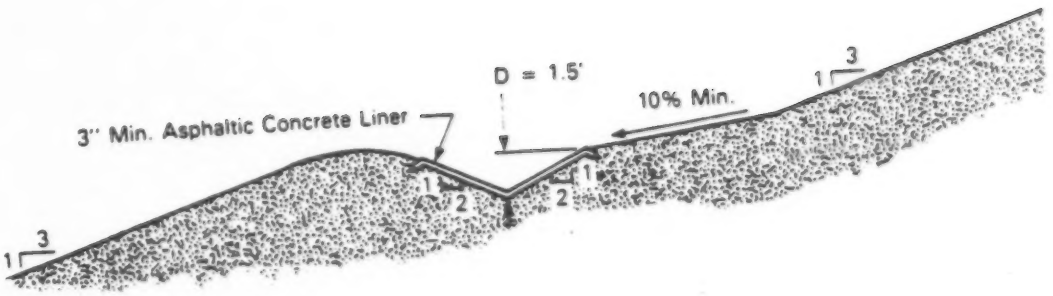
Bench terraces do not necessarily have to be designed with diversions or ditches to intercept flow. Reverse benches and slope benches, as shown in Figure 5-8 may be constructed on well-stabilized slopes (e.g., vegetated) to enhance erosion control by reducing slope length and steepness. For sites located in arid regions, these nondrainage benches slow sheet run-on and permit greater infiltration rates, which aid in the establishment of a suitable vegetative cover. For most sites in wet climates where cover erosion is a major problem, benches and terraces should be designed in association with drainage channels that intercept and transport heavy, concentrated surface flows safely off-site (JRB Associates, 1982b).

As with other earthen erosion control structures, benches and terraces should be sufficiently compacted and stabilized with appropriate cover (grasses, mulches, sod) to accommodate local topography and climate. They should be inspected during or after major storms to ensure proper functioning and structural integrity. If bench slopes become badly eroded or if their surfaces become susceptible to ponding from differential settlement, regrading and sodding may be necessary (JRB Associates, 1982b).



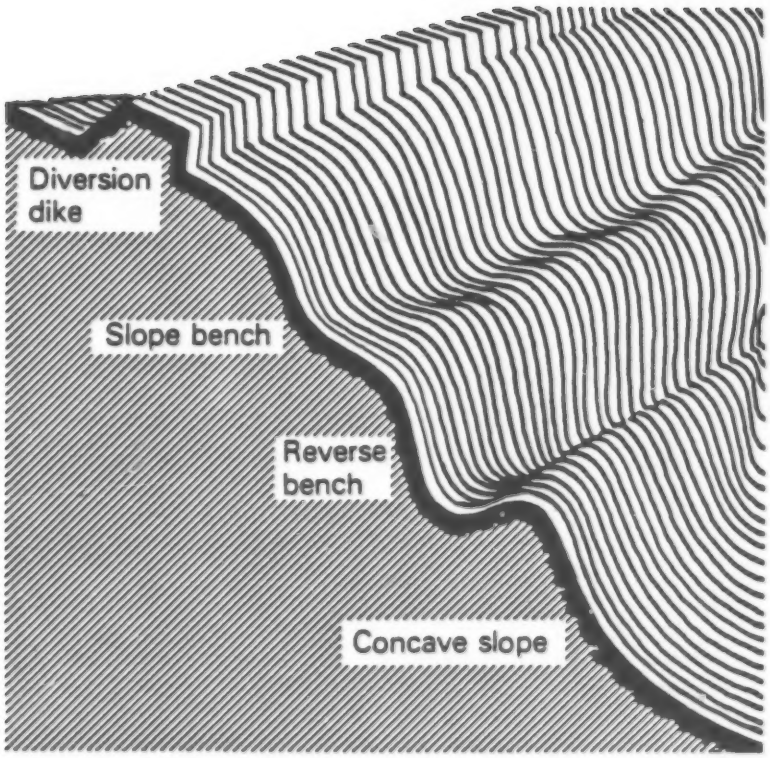
Source: JRB Associates, 1982b

FIGURE 5-6. BENCH TERRACES WITH REVERSE FALL



Source: JRB Associates, 1982b

FIGURE 5-7. TYPICAL DRAINAGE BENCH



Source: JRB Associates, 1982b

FIGURE 5-8. SLOPE REDUCTION MEASURES

Installation--

Installation of terraces and benches will typically involve regrading the area surrounding the site of concern. Options that only involve regrading and stabilization will be easier and less costly than options requiring off-site materials.

Site-specific factors also affect the installation of terraces and benches. Access is needed to accomodate large scale earth moving equipment associated with terrace and bench construction. Thus, extremely wet areas or areas with limited access may complicate or preclude the use of this option. Additionally, steeper slopes require more extensive drainage networks with larger run-on handling capacities. Vegetatively disturbed areas also require more extensive drainage areas as the control provided by natural cover is removed.

Terraces and benches generally do not pose any problems with respect to final response actions. Terraces and benches may not have to be removed, but can easily be regraded should they impede site access. Temporary terraces and benches may actually remain and be improved upon for final response actions.

Costs--

The costs of temporary terraces and benches are largely dependent upon the following factors (JRB Associates, 1982a, JRB Associates, 1982b):

- o Extensiveness of area requiring drainage
- o Steepness of slope
- o Amount and type of non-local materials needed (e.g., cement, asphalt, synthetic liners, and clay)
- o Difficulty of access to the area (especially for heavy machinery)
- o Extent of existing drainageways contributing to the problem and of areas not covered by vegetative manner resulting in increased drainage.
- o Severity of weather patterns (e.g., storms).

Unit costs for terraces and benches are provided in Table 5-1.

Levees and Floodwalls

Levees are earthen embankments that function as flood protection structures in areas subject to inundation from tidal flow or riverine flooding. Levees create a barrier to confine floodwaters to a floodway and to protect structures behind the barrier. They are most suitable for installation in flood fringe areas or areas subject to storm tide flooding, but not for areas directly within open floodways (JRB Associates, 1982b).

Flood containment levees may be constructed as perimeter embankments surrounding sites located in floodplain fringe areas, thus providing an extra

measure of secondary containment. Levees may be installed at the base of impoundments along slope faces subject to periodic inundation. Levees provide long-term protection from floodwaters that may fill impoundments or erode impoundment walls allowing the transport of waste materials off-site (JRB Associates, 1982b).

As noted previously, levees and floodwalls are distinct from diversion dikes and berms in the context of this discussion. Levees and floodwalls are used to control larger volumes associated with flood and tidal waters. Diversion dikes and berms are used to control much smaller volumes of water associated with run-on.

Design--

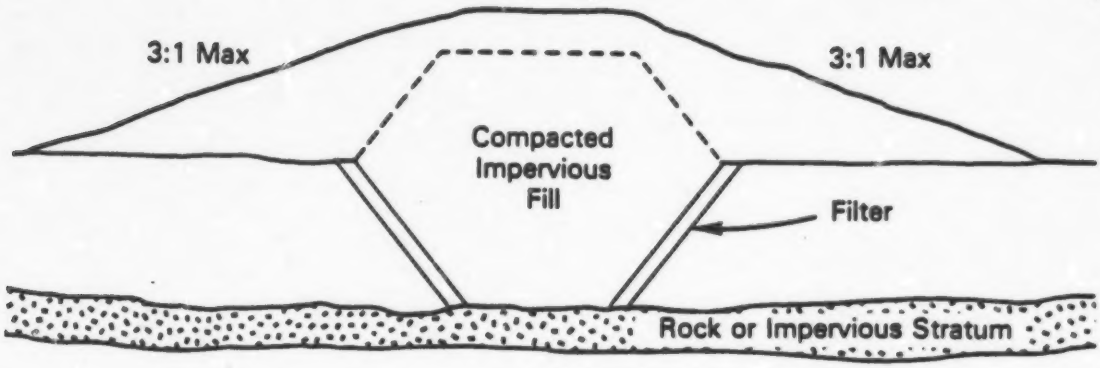
Levees are generally constructed of compacted impervious fill. Special drainage structures are often required to drain the area behind the embankment. While levees are normally constructed for long-term flood protection, they require periodic inspection and maintenance to assure proper functioning. They may be costly to build and maintain, but if properly designed on a site-specific basis, levees will reduce flooding hazards at critical waste impoundment areas (JRB Associates, 1982b).

To provide adequate flood protection, levees should be constructed to a height capable of containing a flood of 100-year magnitude. Levees designed to protect areas from maximum flood levels of lesser magnitude/greater frequency (e.g., 50-year flood) may not provide sufficient flood protection, particularly for sites known to contain large quantities of hazardous wastes.

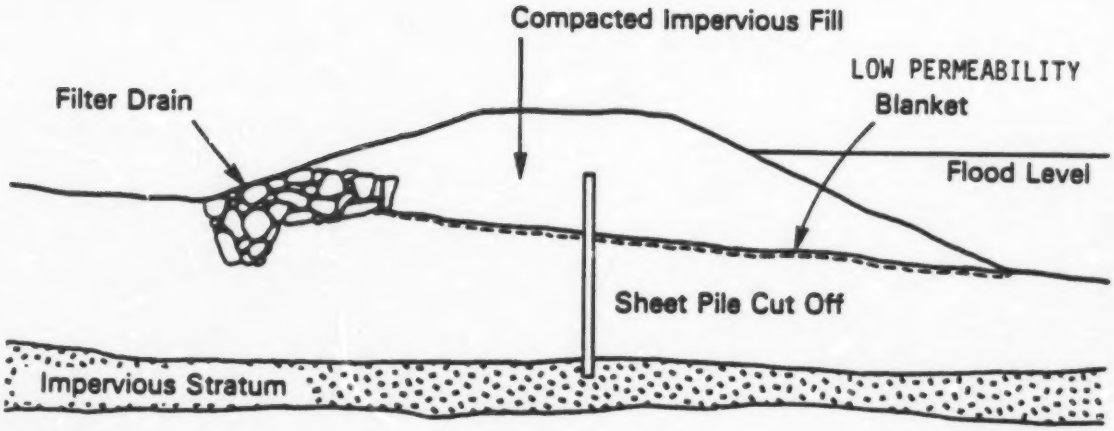
Levees are ideally constructed with erosion-resistant, low-permeability soils, preferably clay. Most levees are homogeneous embankments constructed of local materials; if impermeable fill is lacking, or if seepage through and below the levee is a problem, then construction involving a compacted impervious core or sheet-pile cut-off extending below the levee to bedrock (or other impervious stratum) may be necessary. Figure 5-9 depicts these two special cases. Excess seepage through the levees should be collected with gravel-filled trenches or tile drains along the interior of the levee. After draining to sumps, the seepage can be pumped out over the levee. Levee bank slopes, especially those constructed of less desirable soils (silt, sands), should be protected against erosion by sodding, planting of shrubs and trees, use of stone rip-rap (JRB Associates, 1982b).

Fill material used in levee construction should be compacted in layers, with the least pervious layer along the riverside of the levee. Because the use of levees reduces floodplain storage capacity, fill material should be dredged from borrow pits within the floodplain to provide alternative storage volume for floodwaters. This measure will help control rising floodpeaks and prevent an increase in depth of the downstream flood stage (JRB Associates, 1982b).

Storm run-on from precipitation falling on the drainage area behind the levee may cause backwater flooding of levees. To handle such interior drainage, up-slope interceptor ditches, diversion, or grassed waterways can be used to



LEVEE WITH IMPERVIOUS CORE



LEVEE WITH CUTOFF AND DRAIN

Source: JRB Associates, 1982b

FIGURE 5-9. LEVEE CONFIGURATION

channel run-off to down-slope holding basins for subsequent pumping or to off-site streams for natural discharge. Another method to handle backwater flooding is the installation of pressure conduits with up-slope intake works that discharge beneath the levee. These conduits should be equipped with tidal gates or backwater valves to prevent back-flow and regulate discharge (JRB Associates, 1982b).

Because of the relatively long, flat side slopes of levees, an embankment of any considerable height requires a very large base width. For locations with limited space and fill material, or excessive real estate costs, the use of concrete floodwalls is a preferable alternative to levee construction. Floodwalls should be designed to withstand the hydrostatic pressure exerted by water at the design flood level. As they are subject to flood loading on one side only, floodwalls require solid foundations. Figure 5-10 presents typical floodwall sections. Like levees, floodwalls may require sub-surface cut-offs and interior drainage structures for excessive seepage or backwater flow (JRB Associates, 1982b).

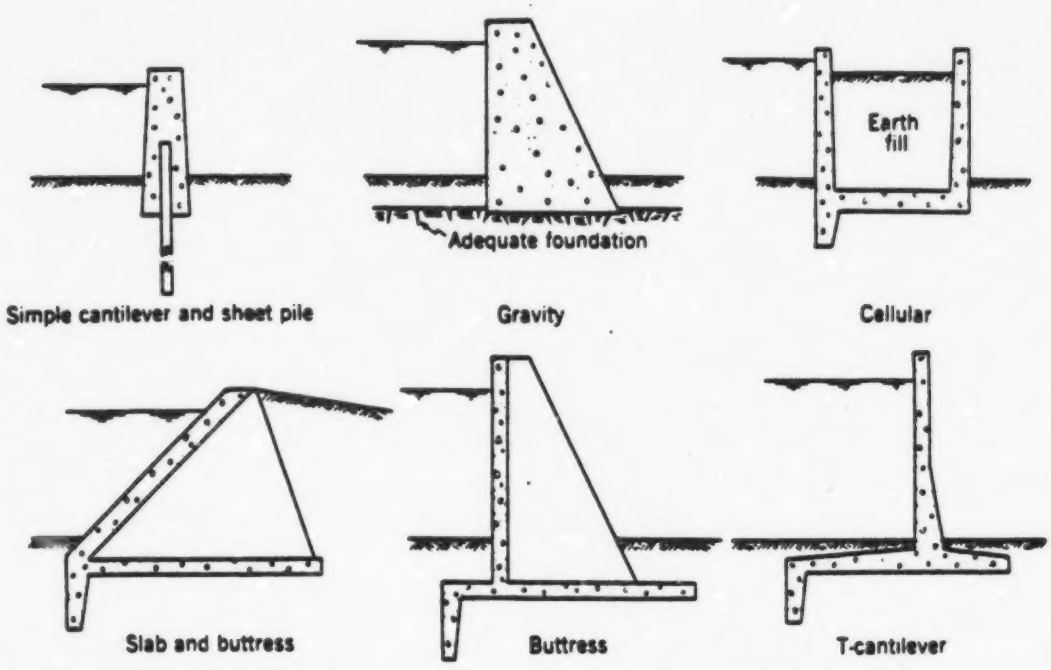
Levees and floodwalls subjected to excessive flooding require regular inspections and maintenance to detect and repair any erosion or breaches. Failure of a levee during a major flood requires costly emergency measures (e.g., emergency emankments or sand bags) that can possibly expose workers to wastes. Such measures may have limited success in mitigating the impacts of released wastes (JRB Associates, 1982b).

Installation--

Levee and floodwall installation generally involves the use of area materials for construction. Site and impoundment characteristics may require the use of non-local materials. As materials may have to be removed and/or placed in wetlands, a dredge and fill permit may be necessary under Section 404 of the Clean Water Act. This issue of whether such a permit is necessary has not been resolved as of the date of this publication and is still being negotiated between the EPA and the Army Corps of Engineers.

Site access may provide problems in installing a levee or floodwall. Because large quantities of earthen materials have to be moved, the area must be able to support heavy machinery. This may be a problem in wetland areas, particularly in warmer and wetter climates. Installation problems may be greatly aggravated if the impoundment is wholly or partially surrounded by water; this would increase construction costs.

Levees and floodwalls may pose some problems for implementing a final site action. Should the structures surround the site, they may need to be breached to gain access to the impoundment. However, it is likely that the structures will not have to be entirely removed for the final response action as flood protection may still be required. Should waste materials be wholly removed, regrading the site will require demolition of flood protection structures.



Source: JRB Associates, 1982b

FIGURE 5-10. TYPICAL FLOODWALL SECTIONS

Costs--

The costs of levees and floodwalls are largely dependent upon the following factors:

- o Extensiveness of area requiring flood protection
- o Accessibility of site
- o Extent of protection required (e.g., the entire perimeter or just a portion thereof)
- o Proximity of site to floodplain
- o Frequency and extent of flooding
- o Amount and type of non-local materials needed (e.g., cement, asphalt, synthetic liners, clay, etc.)
- o Design life of structures
- o Available area.

Unit costs for levees and floodwalls are provided in Table 5-1.

IMPOUNDMENT WALL CONSTRUCTION AND REPAIR

Overtopping controls discussed in this section involve improvements to surface impoundment walls to prevent wastes from leaving the impoundment. When designed, constructed, and maintained correctly, these controls can extend the useful life of the impoundment by either maintaining or increasing its capacity until final response actions are implemented. Overtopping controls discussed within this section involve:

- o Impoundment dike and berm repair: improvements to impoundment walls to maintain impoundment capacity.
- o Dike and berm construction: increasing the height of berms to increase impoundment capacity.

These options are discussed in more detail below.

Impoundment Dike and Berm Reconstruction

Dike and berm reconstruction is performed in situations where the external or internal impoundment wall degradation has reduced the effective capacity of the surface impoundment. The purpose of this method of overtopping control is to restore the original impoundment capacity and prevent further overtopping of the impoundment contents. This method is typically used where impoundment walls have significantly degraded due to contact with impoundment liquids or external forces (e.g., rain) and there is a threat of overtopping; it does not address situations where impoundment contents are leaking through the walls.

In addition, reconstruction is often the foundation upon which other options are later applied.

Reconstruction techniques may also be applied to surface drainage controls (i.e., to diversion and interceptor dikes and berms). However, this section does not address these applications.

Design--

Specific design and construction criteria for reconstruction of surface impoundments walls depend upon site-specific variables. First, the cause and site of wall degradation have to be determined and addressed. Only after this is accomplished can repairs to the structure be made.

External wall degradation caused by surface run-on must first be addressed through external erosion and run-on controls. Ditches and diversions or similar man-made drainage networks may be used to intercept and divert run-on away from an impoundment. Following installation of a drainage network, the impoundment wall can be repaired.

Internal wall degradation resulting from physical and chemical waste contact with the wall requires an alternative approach. First, the contact must be eliminated through the application of cover/liner materials or removal of wastes (e.g., through pumping); minimized through the use of wave and wind controls such as covers, baffles, or similar mechanisms; or neutralized through waste treatment. After addressing physical and chemical contact of lagoon contents with the impoundment, the walls can be repaired.

Repairs made to the impoundment wall can vary in scope and complexity but depend upon the damage that has been done. For example, minor cracks in man-made impoundment walls (e.g., cement) may be repaired by filling or patching. Vegetation growing on the impoundment bank may have to be killed but not necessarily removed as excavation of root systems may further weaken the wall. Major breaches resulting from flooding or run-on-induced erosion may require replacement of a major portion of the wall.

In each of the above scenarios, repairs should attempt to restore the integrity and working capacity of the impoundment. Due to the diverse nature of possible repairs required, a detailed design discussion is not included. However, repairs to the wall would generally follow the requirements set forth in constructing the walls.

Where significant construction would be necessary, it may be more cost-effective to conduct minor repairs, pump down the lagoon, and continue to use the lagoon at a lesser capacity. This option would depend on site-specific criteria such as the need for full lagoon capacity.

Installation--

The implementation of repairs is dependent upon the extent of restoration required. Factors influencing the repairs include: location of breach and/or wall degradation (e.g., internal vs. external); ability of existing structures

to support reconstruction activities (e.g., heavy machinery and compaction activities); reconstruction materials selected (e.g., local vs. off-site); extent of vegetation to be destroyed prior to repairs; and difficulty of site access (e.g., lack of roadway for heavy machinery).

Costs--

Costs are also highly dependent upon the extent and type of reconstruction needed. Factors influencing the costs are similar to those identified for interceptor and diversion dikes and berms. Due to this variability, specific unit costs cannot be cited. Table 5-1 contains costs associated with activities that may be included in selected reconstruction options.

Increasing Impoundment Wall Height Through Dike and Berm Construction

Dikes and berms may be used to increase the impoundment wall height in order to increase the available capacity of the impoundment. In a typical application, materials contained within the impoundment may fill the available capacity and pose an immediate threat of overtopping. The probable cause of overtopping is likely to be excessive precipitation or further contribution of wastes.

Design--

Design criteria for dikes and berms used to increase the capacity of the impoundment are similiar for diversion and interceptor dikes and berms. Materials of construction should be of erosionresistant, low permeability, clayey soils. It is preferable to use on-site materials. Unlike diversion and interceptor dikes and berms, compacted sand and gravel is unsuitable for structures designed to raise the impoundment wall. Seeding and mulching of the exposed portions of the dikes and berms may increase the design life of the structures, which is approximately one year. The use of synthetic liners extending over the new dike or berm and anchored below the liquid level or the existing wall will also extend the life of this interim measure.

As with diversion and interceptor dikes and berms, structures built to increase the capacity of the impoundment should have a top width of at least two feet. The height should provide sufficient capacity to allow for rain/run-on expected until the final action is initiated. Sufficient freeboard (about two feet) should also be provided as a safety factor. The grade should allow for positive drainage of run-on but less than that of the impoundment wall upon which it is placed. Where possible, the structures should be machine compacted.

Dikes and berms used in this capacity require little maintenance. Erosion is limited to non-flowing liquids within the impoundment (as opposed to diversion or interceptor dikes and berms outside the impoundment) and weathering.

Installation--

As with diversion or interceptor dikes or berms, installation will involve the use of on-site or hauled-in materials and the construction of the structures.

In many cases, materials for construction may be found on-site. Should materials have to be brought in or compacted on-site, access may prove to be a problem. A right-of-way must be available to bring in heavy machinery. Additionally, the site must be able to support the machinery once on-site.

The impoundment walls upon which dikes or berms are to be placed must be wide enough to support the dike or berm. A wider base will be required for greater heights to maintain stable side slopes of 2:1 or greater. Additionally, dikes and berms should be compacted. Where impoundment walls are either too narrow or insufficiently strong to support compaction equipment, dikes and berms may have to be left uncompacted and covered with material (e.g., liner) that is impermeable to the lagoon contents and must be anchored to the supporting wall.

Dikes and berms will likely pose few problems to the final site response action. If not incorporated into the action, they may be leveled to gain access to materials contained within the impoundment.

Costs--

The costs of dikes and berms used to increase impoundment capacity are largely dependent upon the following factors:

- Amount and type of non-local materials needed (e.g., cement, asphalt, or synthetic liners)
- Additional capacity required
- Maintenance and repair required
- Design life of structures
- Amount and type of existing dike or berm stabilization required
- Integrity of existing supporting impoundment walls
- Site access problems.

Unit costs for dikes and berms are provided in Table 5-1.

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APPENDIX A

LIST OF COMPANY ADDRESSES

Air Structures International
30-32 Rockland Park Avenue
Tappan, NY 10983
(914)359-9007

Air-Tech Industries
9 Brighton Road
Clifton, NJ 07012
(201)460-9730

Burke Industries, Inc.
2258 South Tenth Street
San Jose, CA 95112
(408)297-3500

Butler Manufacturing Company
BMA Tower, Penn Valley Park
Kansas City, MO 64141
(816)968-3000

Globe Linings Inc.
1901 East Wardlow Road
Long Beach, CA 90807
(213)426-2587

Seaman Building Systems
2028 E. Whitfield Avenue
Sarasota, FL 33580
(813)756-8463

Shenango Steel Buildings, Inc.
307 Carbaugh Street, P.O. Box 268
West Middlesex, PA 16159
(412)528-9925

Sprung Instant Structures, Inc.
420 South Balavia Avenue
Balavia, IL 60510
(312)879-6101

Thermo-Flex Inc.
P.O. Box 1184
Salina, KS 67402
(913)827-7201

APPENDIX B

CONVERSION FACTORS

Quantity	Equivalent Values		
Mass	1 kg	or	1000 g 0.001 metric ton 2.20462 lb_m 35.27392 oz
	1 lb_m	or	16 oz 5×10^{-4} ton 453.593 g 0.453593 kg
Length	1 m	or	100 cm 1000 mm 10^6 microns 10^{10} angstroms 39.37 in 3.2808 ft 1.0936 yards 0.0006214 mile
	1 ft	or	12 in 1/3 yd 0.3048 m 30.48 cm
Volume	1 m^3	or	1000 liters 10^6 cm^3 10^6 ml 35.3145 ft^3 220.83 imperial gal 264.17 gal 1056.68 quarts
	1 ft^3	or	1728 in^3 7.4805 gal 0.028317 m^3 28.317 liters 28,317 cm^3

(continued)

CONVERSION FACTORS (continued)

Quantity	Equivalent Values		
Force	1 N	or	1 $kg\text{-}m/s^2$ 10^5 dynes 10^5 $g\text{-}cm/s^2$ 0.22481 lb_f
	1 lb_f	or	32.174 $lb_m\text{-}ft/s^2$ 4.4482 N 4.4482×10^5 dynes
Pressure	1 atm	or	1.01325×10^5 N/m^2 (Pa) 1.01325×10^6 $dynes/cm^2$ 760 mm Hg @ 0°C (torr) 10.333 m H_2O @ 4°C 29.921 in Hg @ 0°C
Energy	1 J	or	1 N-m 10^7 ergs 10^7 dyne-cm 2.778×10^{-7} kW-hr 0.23901 cal 0.7376 $ft\text{-}lb_f$ 9.486×10^{-4} Btu
Power	1 W	or	1 J/s 0.23901 cal/s 0.7376 $ft\text{-}lb_f/s$ 9.486×10^{-4} Btu/s 1.341×10^{-3} hp

CONVERSION FACTORS (continued)

Quantity	Equivalent Values		
Force	1 N	or	1 $kg-m/s^2$ 10^5 dynes 10^5 $g-cm/s^2$ 0.22481 lb_f
	1 lb_f	or	32.174 lb_m-ft/s^2 4.4482 N 4.4482×10^5 dynes
Pressure	1 atm	or	1.01325×10^5 N/m^2 (Pa) 1.01325×10^6 $dynes/cm^2$ 760 mm Hg @ 0°C (torr) 10.333 m H_2O @ 4°C 29.921 in Hg @ 0°C
Energy	1 J	or	1 N-m 10^7 ergs 10^7 dyne-cm 2.778×10^{-7} kW-hr 0.23901 cal 0.7376 $ft-lb_f$ 9.486×10^{-4} Btu
Power	1 W	or	1 J/s 0.23901 cal/s 0.7376 $ft-lb_f/s$ 9.486×10^{-4} Btu/s 1.341×10^{-3} hp